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Medal Day Proceedings at The Franklin Institute

The Humane Qualities of Science

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VOL. 272 NO. 6

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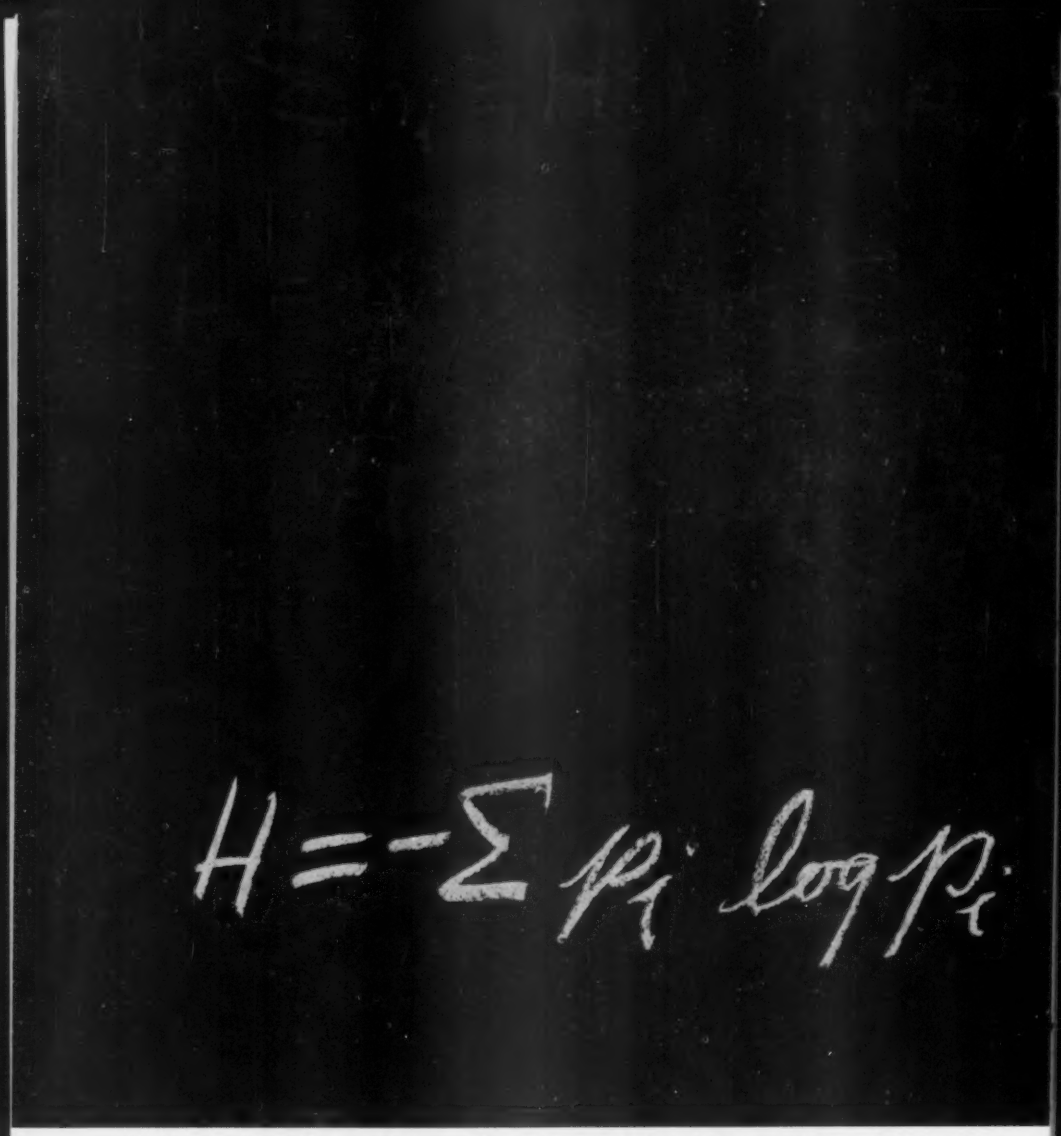

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SEPARATION OF FLOW

BY

PAUL K. CHANG[1]

SUMMARY

Flow separation is perhaps the most important unsolved phenomenon of fluid mechanics which causes energy loss and deviation of stream lines. A summary of flow separation is presented in order to understand the basic problem, the present state of knowledge and to indicate future development. The review of the analytical and experimental investigations from more than one hundred classical and current references is made covering the whole region of flow separation—laminar, turbulent, incompressible and compressible flow.

INTRODUCTION

Separation of flow or stall is a very important viscous fluid phenomenon which causes energy loss accompanied by deviation of stream lines and reverse flow. The definition of stall may be referred to any reverse flow at a wall and stall may be viewed as a spectrum of states with many possible geometries and transient elements. For external flow, the separation of flow increases drag and decreases lift; for internal flow, stall reduces efficiency. Since malfunctions of downstream components are caused due to separation of flow and the maximum pressure recovery can be obtained at or near stall, it is essential from a practical point of view to understand and predict stall in order to design optimum fluid devices. However, the problem of stall is very complex and despite a great deal of research efforts, mainly based on boundary-layer theory and experiments, stall remains the most common unsolved problem of fluid mechanics whose solution can be applied to engineering design (1).[2] Recent researches reveal that present-day boundary-layer theory is not able to solve the problem of separation and that stability considerations should be added to obtain a satisfactory solution (2, 3). A review of 33 references on available physical data and a discussion of flow in passage on the problem of stall are given by Kline (3). Town-

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[2] The boldface numbers in parentheses refer to the references appended to this paper.

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send (4) summarized available data on turbulent shear layers and turbulence. Since, however, the most promising approach to the solution appears to be a systematic gathering of data involving qualitative and clear visualization (1), a more general and extensive survey of classical and recent references is made in this paper.

I. MECHANICS OF FLOW SEPARATION AND ITS BASIC PROBLEM

Prandtl (5) states clearly that the necessary condition for flow separation from the wall is increasing pressure, that is, the adverse pressure gradient. The forward velocity and momentum near the wall are small because of viscosity. Downstream the small amount of momentum and energy along the body surface is used up to overcome pressure and friction. Finally, the fluid particles are brought to rest and begin to leave the surface. Further downstream the fluid flows in the reverse direction. Because of this reverse flow the stream-line diagram changes, leaving a separated region, usually filled with vortices of small velocity.

Classical theory predicts flow separation at a point $(\partial u/\partial y)_{y=0} = 0$, where u is streamwise velocity and y is distance normal to the surface. Recent investigations (1) show that for laminar flow classical prediction gives a reasonable result, but a more accurate solution is achieved if the pressure distribution is based upon actual rather than potential flow. For turbulent flow, several analytical methods are available for prediction of flow separation but a study of similarity and empirical methods shows that, to date, a truly adequate method has not been developed (6, 7). The missing information in many geometries is knowledge of stable flow (3) and how to predict the disturbance wavelength of stall propagation (8). A regular, periodic, and relatively simple type of flow pulsation is called stall propagation. Classical steady boundary-layer theory is a powerful tool but this theory alone is insufficient to predict or explain stall (1, 2, 8). In addition to boundary-layer concept, the stability of the over-all flow pattern, particularly as affected by mixing between main stream and wall layers, is important to determine stall characteristics. The following observations may serve to illustrate the flow phenomena which classical boundary-layer theory is not able to explain or to predict and to be solved as basic problem by additional considerations. Cochran (9) observed four flow regimes in simple plane-wall two-dimensional diffusers as the included angles varied.

1. A regime of well-behaved unseparated flow.
2. A regime of large transitory stall in which the separation varies in size, intensity and location with time.
3. A regime of essentially two-dimensional, relatively steady, fully developed stall in which the flow flows with little or no expansion.
4. A regime of jet flow in which flow separates and proceeds in a fashion similar to that of free jet.

Emmons, Kronauer and Rockett (8) observed stall propagation, in an axial compressor. At certain fixed operating points of a compressor several different stall patterns exist and transitions from one pattern to another occur spontaneously, reversely and fairly frequently.

In order to establish a completely reliable prediction of stall, additional studies are necessary, not only of the mean flow but also of transient characteristics of both boundary layer and of stall (1). Emmons (8) states that a relatively simple mathematical model offers the possibility of determining all the important features of stall.

For a supersonic flow, a shock-wave boundary-layer interaction also causes flow separation. In a shock region a considerable pressure gradient exists along a normal to the wall; this is of negligible magnitude for the subsonic boundary layer.

II. SEPARATION OF LAMINAR FLOW

Flow separation around a circular cylinder and a sphere occurs at 80–85° from the stagnation point in a range of Reynolds numbers from 10^3 to 10^5. In this range, drag is predominantly due to pressure and C_D is approximately constant (11, 12). Prandtl (13) measured $C_D = 0.44$ for a sphere with laminar flow separation. Hiemenz (14) computed the point of laminar separation on a circular cylinder at 82° and Pohlhausen (15) at 81.5° from the stagnation point. Schlichting and Uhlrich (16) determined analytically the laminar separation points on elliptical cylinders as functions of the ratio of major to minor axes.

The available analytical methods for the prediction of two-dimensional laminar separation may be summarized as follows: in Von Karman-Millikan's approximate method (17), an inner solution, applicable in the neighborhood of the wall, is matched with an outer solution, applicable at the outer region of the boundary layer, to determine a laminar separation point. Numerical computation of the outer solution is worked out by Von Doenhoff (18). Introducing the equivalent length of a flat plate, Von Doenhoff (19) developed a simple approximate method. A comparison of Pohlhausen's criterion of laminar flow separation (15) with experimental data of Schubauer (20) on an elliptic cylinder showed poor agreement, although the same criterion yields a good result on laminar flow separations around a circular cylinder. Görtler's (21) method is mathematically rigorous, and his solution is used by Curle and Skan (22) to modify Stratford's criterion (23) of separation to $x_1^2 c_p \left(\frac{dc_p}{dx_1}\right)^2 = 0.0104$, where x_1 is a distance along the surface from the starting point of pressure rise and c_p is a pressure coefficient. Shvets (24) formulated the criterion as $\left\{4\left(\frac{du}{dx}\right) \Big/ U^6\right\} \int_0^x U^5 dx = -1$, where U is the streamwise velocity at the edge of boundary layer, and x is a distance along the surface from the stagnation point in terms

of velocity only. However, Thwaites' criterion (25), modified by Curle and Skan (22), contains viscosity terms and is given by $-\frac{\theta^2}{\nu}\frac{dU}{dx} = 0.09$, where θ is momentum thickness of boundary layer and ν is kinematic viscosity. A comparison of experimental data and analyses by the methods of Stratford, Shvets, and Thwaites on two groups of thin and thick symmetrical struts shows that a good agreement can be obtained among them (26, 27). A simple formula for laminar separation is also given by Tani (28). The magnitude of velocity gradient sufficient to cause a laminar flow separation is given by Prandtl (5) in which $UU''/U'^2 < 11$ where the primes denote derivatives with respect to x.

The criterion of three-dimensional laminar flow separation is difficult to formulate (29, 30). For the yawed infinite wing, Wild (31) found that a spanwise component of flow does not influence separation and, for the yawed, infinitely long cylinder, Sears (32) concluded that the location of laminar separation of the chordwise flow is independent of yaw. Jones' (33) investigation on a yawed or swept wing of very high aspect ratio shows that the separation phenomena are determined by the crosswise velocity component, and the effect of sweepback is to increase the area of stable laminar flow and to decrease the lift coefficient at which flow separation occurs. Along a separating stream line of three-dimensional flow $\partial p/\partial z = 0$, where p is static pressure and z is the coordinate of the crossflow. Timman (34) indicates that this separating line is the envelope of the wall stream lines inside the boundary layer. Sears (32) predicted that at the position of three-dimensional flow separation the skin friction is not zero. Eichelbrenner and Oudart (35) succeeded in determining this, experimentally, in the three-dimensional envelope of the wall stream lines. Küchemann (36) states that on sheared wings the stream lines inside the boundary layer are not parallel to those in the external flow, and, because of the existence of a cross flow, separation does not necessarily occur in the same manner on an unswept wing.

The research programs on flow phenomena in the region of separated flow are important to the understanding of transition, reattachment, and shock interaction with boundary layer. Goldstein (37) and Jones (38) have done much to clarify the flow phenomena on the upstream side in the vicinity of separation. Gault's (39) experiment shows that the turbulence level causes little change in the position of laminar separation, but the increased level of turbulence reduces the extent of separated laminar flow near the leading edge. Bursnall and Loftin (40) showed experimentally that localized region of laminar separation can be characterized by a length of laminar boundary-layer flow separation, after which transition occurs. They found that the turbulent boundary layer spreads and reattaches to the surface. This experiment was con-

ducted on NACA 663–018 airfoil section at Reynolds numbers from $1.2 \cdot 10^6$ to $2.4 \cdot 10^6$. It is indicated that the length of separated laminar layer before transition occurred could be expressed in terms of the boundary-layer Reynolds number of the separation point. In the leading-edge separation of a thin airfoil, Owen and Klanfer (41) observed the larger laminar-type bubble at $K_{\delta_s^*} < 500$ (Reynolds number based upon displacement thickness at separation) and the shorter turbulent-type bubble at $K_{\delta_s^*} > 500$. Cramer (42) computed the laminar-separation bubble length of a stepped plate model. Chang (26) measured laminar separation points on two groups of thick and thin, geometrically similar struts, and confirmed that the point of laminar separation is independent of free-stream Reynolds numbers if the geometry of the struts is similar. Eichelbrenner and Werlé (43) observed, on two NACA 6A series airfoils, that the angle of laminar flow separation increases if the flow velocity decreases. This fact is shown analytically. However, since the angle is very small, it may be approximated that the separating stream line leaves the body surface tangentially (44).

Reattachment of separated flow takes place at $R_\delta > 1200$ (45) or at $R_{\delta^*} > 400$ to 500 (40), where δ is boundary-layer thickness and δ^* is boundary-layer displacement thickness. With emphasis on the effect of transition, Chapman, Kuehn and Larson (46) investigated, experimentally and theoretically, the flow separation associated with steps, bases, compression corners, curved surfaces, shock-wave boundary-layer reflections, and configurations producing leading-edge separation. The experiment was carried out in the range of Mach numbers from 0.4 to 3.6 and of Reynolds numbers from 4000 to 5.10^6. The location of the transition relative to the reattachment and separation position is dominant in controlling the characteristic features of pressure distribution. Classification is made of each separated flow into one of three regimes: pure laminar with transition downstream of reattachment; transitional with transition between separation and reattachment; and turbulent with transition upstream of separation. Pure laminar separations are steady in a supersonic flow and depend only to a relatively small extent on Reynolds number. The stability of a separated laminar mixing layer increases with an increase in Mach number. Hence, pure laminar separation is of practical interest at hypersonic speeds. Transitional separations were generally unsteady and often depended on Reynolds number. In transitional separation an abrupt pressure rise often occurred at the location of transition. Turbulent separations of supersonic flow were relatively steady and depended only to a minor extent on Reynolds number. The peak pressure rise in turbulent separation depends significantly on model geometry. Leading-edge separation bubble was studied by Crabtree (47), Crabtree, Küchemann and Maskell (48), and by Norbury and Crabtree (49). Flow reattaches

at the rear of the bubble, and, because of the presence of the bubble, the pressure distribution changes in the neighborhood of the leading edge. Crocco and Lees (**50**) developed a mixing theory (the transport of momentum from outer stream to dissipative flow) and showed that the flow-separation problem is basically similar to boundary-layer, shock-wave interaction and wake flow behind blunt-based bodies. The theory indicates that separating flows as well as reattaching flows are capable of supporting a considerable pressure increase at high velocities. Furthermore, in separated flows, the pressure gradient along the surface is a maximum at separation and drops off steeply downstream; in reattaching flow or wake flows, the pressure gradient is negligible some distance upstream of the "reattachment point" and increases rapidly to a maximum as the reattachment point is approached.

III. SEPARATION OF TURBULENT FLOW

The problem of turbulent flow separation is not amenable to analytical treatment; therefore, experimental results were used for its solution. Because of the mixing motion of fluid particles within the boundary layer, turbulent flow is capable of remaining attached to the surface under higher positive pressure gradient than would be possible for laminar flow. The turbulent flow separation for a circular cylinder and a sphere is observed to occur at about 110° from the stagnation point. Boltze (**51**) computed the point of turbulent flow separation around a sphere at 110°.

In the prediction of separation of two-dimensional incompressible turbulent flow, the following criteria may be cited. Buri (**52**) gave $\Gamma = \frac{\theta}{U}\frac{dU}{dx} R_\theta^{1/4} = -0.06$ as a criterion, and Gruschwitz (**53**) presented $\eta = 1 - \left\{\frac{H-1}{H(H+1)}\right\}^{H-1} \geqslant 0.8$ as a criterion, where H is the boundary-layer shape parameter.

Von Doenhoff and Tetervin's (**54**) investigations on airfoil data show that if growth of H is rapid and if H reaches a value of 1.8 to 2.6, then a turbulent flow separation is expected. This method is one of the best known for prediction of turbulent flow separation in the United States. For the evaluation of H a successive numerical integration is needed. Clauser (**6**) found that his simple and well-defined experimental data do not agree with results of the Von Doenhoff-Tetervin method. The details are: Von Doenhoff used a universal family of profiles in which u/U vs. y/θ is plotted. y is the distance normal to the surface. Clauser proved that there is no such universal family. Von Doenhoff used $H = 1.286$ for zero pressure gradient based on the one-seventh power law. Clauser showed that H is not equal to 1.286 for the one-seventh power law and H varies with c_f even for constant pressure. The auxiliary equation which Von Doenhoff applied—

$$\theta \frac{dH}{dx} = e^{4.68(H-2.935)}\left[2\frac{\theta}{\tau}\frac{dp}{dx} - 2.035(H - 1.286)\right]$$

where τ is shear stress, p is static pressure and x is distance along the surface from the point of initial computation—is in disagreement with Clauser's experimental result. Finally, Von Doenhoff assumed that a power law varies with Reynolds number but not with pressure gradient; but Clauser pointed out that the power law is strongly affected by pressure gradient. Clauser (**55**) shows further that H does not express solely the effect of the pressure gradient on the shape of the profile. H is affected as much by skin friction as by pressure gradient. Values of H in the range of 2.2 to 2.6 can be reached on rough surfaces with zero pressure gradient causing no flow separation. Since the boundary layer is nonlinear and has a memory, the one-parameter family idea does not describe all the turbulent boundary-layer behavior in pressure gradient. An exception is the equilibrium profile form, given by $\left(u - \frac{U}{u^*}\right)$ vs y/δ, where u is streamwise velocity within the boundary layer and u^* is friction velocity. Maskell's method (**56**) is more fundamental, and can be computed faster than the theorem of Von Doenhoff and Tetervin (**54**). Maskell used Ludwieg-Tillmann's formula (**57**) of local skin friction coefficient: $c_f = 0.246 \cdot 10^{-0.678H} \cdot R_\theta^{-0.268}$. By extrapolating the values of c_f vs x to a point of $c_f = 0$, the turbulent separation is determined at that point of zero friction. The accuracy of the prediction is claimed within 2 per cent. Garner (**58**) predicts turbulent flow separation at $H = 2.6$. Schubauer and Klebanoff's (**59**) experiment along a wall of an airfoil-like section mounted inside a wind tunnel indicates that the turbulent flow separation takes place at $H = 2.8$. Schuh's (**60**) criterion of $\Delta p/q_1$ of incompressible flow (Δp is static pressure increase from undisturbed flow to separation or to a corresponding characteristic point and q_1 is the initial free stream dynamic pressure) is also applicable to compressible flow. A new method for computation of turbulent flow separation is developed by Kalikhman (**61**). Newman (**62**) measured turbulent boundary layer near separation of a wing, and states that empirical criteria on values of mean flow parameters are inadequate and that turbulent stresses should be better known. Furthermore, his analysis and experiment prove that Von Karman's momentum equation does not apply near separation.

The problem of internal flow separation has been studied recently in the U.S.A. Introducing wake-momentum thickness, Lieblein (**63**) found experimentally that cascade blade stall occurs at minimum loss and at greater angle of attack when the ratio of maximum surface velocity to cascade velocity is about 2. From a study of multi-stage compressors operating in a gas-turbine engine, Lubick and Wallner

(64) found that the surge process in a multi-stage compressor is a step-by-step stalling of the individual compressor stages. These stages are stalled at the same critical pressure ratios during quasi-static increases in loading as during very rapid transients in inlet flow. Stall may be predicted for disturbance at the front or at the rear of the compressor, regardless of the rate of loading change.

The problem of separation of flow around a three-dimensional body such as a ship's hull with finite draft is a desirable future research program of practical use.

IV. SEPARATION OF COMPRESSIBLE FLOW

The problem of separation of compressible flow is complex, and, in addition, it involves compressibility effect, shock-wave boundary-layer interaction, and aerodynamic heating. The shock wave causes boundary-layer separation and increases pressure drag. Young (65) distinguished five cases of separation phenomena due to shock-wave boundary-layer interaction:

1. Laminar flow ahead of the shock remains as laminar flow and unseparated behind the shock.
2. Laminar flow ahead of the shock separates in front of the shock and reattaches to the surface as laminar or turbulent flow.
3. Laminar flow ahead of the shock separates in front of the shock and does not reattach to the surface.
4. Turbulent flow ahead of the shock does not separate.
5. Turbulent flow ahead of the shock separates.

Among the numerous references on flow separation of compressible flow, only the following are selected for brief survey. The difference between the flow separation with incompressible and compressible flows may be illustrated as follows: if the effect of Mach number is small, separation occurs at smaller angles of attack with compressible flow than with incompressible flow (66).

Transonic flow separation was studied by Pearcey (67). The experiment of Bogdonoff and Kepler (68) shows that the point of turbulent flow separation and the pressure ratio at separation are independent of shock strength when the latter is larger than 2.5. The pressure rise across the shock, required to cause separation on a flat plate, was investigated by Donaldson and Lange (69) by dimensional study and experiment. The results are: the required pressure rise is proportional to skin friction, and critical pressure rise varies as the Reynolds number to the $-1/2$ power for laminar boundary layers and as the Reynolds number to the $-1/5$ power for turbulent boundary layers. Howarth (70) analyzed the compressibility effect on separation for a case of main stream velocity that starts from a stagnation point, rises to a maximum, and then falls. From this analysis it is concluded that, for such a

velocity distribution, increasing compressibility will cause earlier separation than with incompressible flow, given the same velocity distribution. Lange's (**71**) and Love's (**72**) experiments show that for a range of Mach numbers from 1.55 to 3.03 and Reynolds numbers from 2.10^6 to 2.10^7, the peak pressure-rise coefficient associated with the separation of turbulent boundary layer produced by forward-facing steps is nearly independent of Reynolds number. Mager (**73**) proved that Love's (**72**) finding is in close agreement with the semi-empirical rule for computing the incompressible turbulent boundary layer. Fage and Sargent (**74**) found that for a normal shock with a pressure rise of 1.8 and $M = 1.3$ there is no separation. From Young's (**75**) analysis it may be stated that for shock-induced separation a pressure rise of 1.05–1.1 is required for laminar flow and a pressure rise of 1.7–1.8 is required for turbulent flow. On the cylindrical bodies, flow separation is caused by trailing-edge shock (**76**). For a laminar boundary layer a number of individual shock waves form a shock-wave region, but for a turbulent boundary layer only one normal shock wave exists (**77**, **78**). Busemann (**79**) observed that, along a diffuser wall, flow separation depends neither on the angle of convergence nor on the angle of divergence but always on the pressure gradient. Nussdorfer's (**80**) experiment on supersonic diffusers indicates that single oblique-shock supersonic inlets, designed to prevent flow separation at the intersection of the normal shock and the boundary layer, could produce approximately the maximum pressure recovery for free-stream Mach numbers up to 2.0. Above a Mach number of 2.0, optimum pressure recovery will not be obtained if separation is to be avoided. Concerning the special topic of flow separation on nose projection in supersonic flight, considerable research has been carried out. One such program is quoted here because of the wide fields covered. Moeckel (**81**) conducted an experiment on a spherical-nosed, axisymmetric body with slender rods projecting upstream of the nose in the range of Mach numbers from 1.76 to 2.10. For small tip projections the flow separated near the tip of the rod, whereas for larger tip projections, separation took place on the rod surface. A spiked blunt body, at supersonic and hypersonic speeds, reduced the drag considerably, when compared with the drag of an unspiked blunt body. The smallest drag was obtained with rod-tip projections equal to about three times the nose radius. Loftin and Wilson (**82**) developed a rapid analytical method for the computation of the separation point of a compressible laminar boundary layer. This method is applicable for two-dimensional flow and is an extension of Von Doenhoff's solution (**19**) using Stewartson's transformation. Another analytical method, developed by Gadd (**83**), can be used for the determination of laminar separation point by slide rule. Legendre (**84**) studied the problem of leading-edge separation from a flat-plate delta wing. He considered the problem as potential and represented the separation by concentrated vortices.

V. METHODS FOR VISUALIZATION OF FLOW SEPARATION

Visualization of flow around a body or inside a duct is an important method for further understanding of flow separation (3). For the determination of the separated region of complicated three-dimensional body, a simple and accurate technique of flow visualization is essential, because if possible at all, the prediction is very difficult. A summary of flow visualization techniques in wind-tunnel testing is given by de los Santos (85). The well-known methods using tuft, lamp black and kerosene mixture, aluminum powder and the Hele-Shaw methods are relatively simple to apply but the measured results of flow separation by these methods are approximate. For incompressible air flow, the visualization technique by smoke is most widely used (86, 87, 88, 89, 90, 91). For compressible air flow, the method of flow visualization by smoke was developed at the University of Notre Dame. Fluorescent oil film (92) and dust (26, 27, 93) are also used for air-flow visualization. For determination of separated region of any body shape the dust method is particularly useful for its simplicity and accuracy. If fine powder particles are dispersed in the separated region, then these particles are carried upstream to the farthest point by reverse flow, and become attached to the surface when the wall is coated with a thin oil film. In this way the separated region is clearly, accurately and permanently recorded. Two-dimensional transient flow characteristics are better observed by using fluorescent oil film or smoke than dust. For air-dye solution, tuft, polystrol bead air, and milk are used for flow visualization. For compressible continuum, two-dimensional air-flow optical methods are widely used. An extensive review is given in (94) and (95). The chief advantage of the optical methods is that visualization can be made without disturbing or contaminating the flow; the disadvantage is that these methods are not sensitive to the location of the disturbance. The typical arrangement consists of shadowgraph, schlieren and interferometer. The interferometer gives the indications which are proportional to absolute differences in index of densities; schlieren, the density gradients; and the shadowgraph, the rate of change of density gradients. The sharp focus method (96) can be used for any plane along the span; it gives a much clearer picture, eliminating the confusion of equally clear focussed images of waves. For rarefied gas at extremely low density, the previously mentioned optical methods are not feasible for flow visualization; absorption techniques are being developed by Evans and associates at the University of California, in Berkeley (97, 98, 99).

VI. MISCELLANEOUS FINDINGS

When flow separates, the large percentage of total drag is due to pressure drag. Stratford (100) formulated an equation for the computation of two-dimensional pressure drag caused by laminar flow

separation. Similarly, Petersohn (101) formulated an equation for the turbulent flow separation around a body of revolution.

The problem of flow separation affected by heat transfer has been studied by Thomann (102), Morduchow (103), and Gadd (104). An analysis by Morduchow (103) on laminar separation of compressible flow over a transpiration-cooled surface at a uniform wall temperature shows that the separation takes place upstream of the separation point over a heat-insulated wall if the wall and normal mass flow are cooled simultaneously; but at fixed temperature the separation point moves upstream at high Mach numbers. However, Gadd's experiment (104) at a Mach number of about 3 indicates that, in supersonic separating flow with either a laminar or turbulent boundary layer, the pressure distributions are not significantly affected by moderate variations in wall temperature. Yet, the analysis shows that the pressure distributions should have produced appreciable alteration of pressure at the separation point because of the variations of wall temperature.

In order to improve the performance, boundary layer is controlled to delay or prevent the separation. The best-known device for boundary-layer control is the vane, used for wide-angle diffusers and flow turning. Cochran's (9) experiment on flat vanes for a two-dimensional subsonic diffuser shows that a significant reduction in head loss amounting to about 2.5-fold reduction may be obtained and at large angles the pressure-recovery coefficient can be increased from about 0.38 in the unvaned to about 0.7 in the vaned unit. By using vanes, areas of separation can be reduced extensively. For low speed air flow the screen is useful to prevent separation or to restore separated flow in a diffuser. An extensive investigation by Schubauer and Spangenberg (105) shows that by using damping screens in combination with wide-angle diffusers in wind tunnels, separation can be prevented and a high degree of uniformity of flow can be achieved. However, the efficiency of the diffuser is generally low because of the pressure drop through screens. Boundary layer can also be controlled by injection of momentum (106, 107), by means of a vortex generator (108, 109) or mixers other than a vortex generator, by using a wedge-shaped body (110), by distributing suction (111), by using the swirl technique, or by the Russian method of grooving the body surface.

As a particular application of flow separation to diffuser design, Stratford (112) designed a diffuser inner contour on which the value of friction approaches zero. On such a surface the flow is on the brink of separation adhering to the surface.

This concludes the brief survey of present knowledge on separation of flow. Besides the basic problems there are many subjects of flow separation to be solved. Among them the problems of unsteady, three-dimensional, curved jet and hypersonic flow separation may be pointed

out. A reduction of drag by sound energy is another potential research program the for future.

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IRREGULAR AND BARRED SPIRAL NEBULAE

BY

C. E. R. BRUCE[1]

SUMMARY

The writer's electrical discharge theory is shown to afford an explanation for the irregular and barred spiral galaxies, and in particular for Hubble's Type SBa, and for the corresponding forms observed in many planetary or spiral stellar nebulae. It accounts for the "cataclysmic action," referred to by Hubble as apparently occurring in his scheme of galactic evolution, and for the fact that the arms are not seen in process of formation in Type Sa. It also accounts for the absence of Population I stars in the older and larger elliptical galaxies, and suggests an explanation for the increased proportion of heavy atoms in Population I stars. It accounts for observed intergalactic forces more than 10^{3} times those of gravitation, and acting at right angles to these last. The theory also offers a strong argument in favor of an evolutionary universe, as opposed to continuous creation, and affords a basis for the major evolutionary principle—the accretion of atmospheric matter by the magnetic pinch effect. The theory yields a value for the total energy radiated from a radio galaxy which is in close accord with estimates derived from observations.

1. INTRODUCTION

In two earlier contributions (**1a, b**)[2] the writer has shown that his electric field and discharge theory of cosmic atmospheric phenomena and universal evolution (**1c**) affords an explanation for many of the phenomena observed in the atmospheres of stars and galaxies. It has led to a series of predictions which have not had long to wait for their observational confirmation. Indeed, had the writer but known it, some of the observations were already available before the theoretical deductions were made. In the original account (**1c**) for example, it was suggested that electrical breakdown occurs in the atmospheres of globular and elliptical nebulae, which last are thereby transformed into spiral galaxies. Unbeknown to the writer, such a galactic discharge had already been photographed in the globular nebula NGC 4486 in 1918 (**2**). However, it was only when this galaxy was discovered to be a radio source—Virgo A—that the subsequent photograph taken at Mount Wilson and shown in Fig. 3 of (**1a**) became well known. This shows the discharge channel which is the main source of the radio noise. It is a cosmic thermonuclear discharge, 6,000 million million miles long, at a temperature of about 400,000,000° K (**1a**), and extending at the rate of 2,500 miles per second, and it will go on doing so for ten or a hundred million years.

[1] Electrical Research Association, Leatherhead, Surrey, England.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

The radiation from this electrical discharge and the surrounding atmosphere is naturally "colossal"—perhaps this suspect word is justified under these circumstances. It has certainly posed problems to the astrophysicist for which dire solutions have been proferred. For example, the following (3) was written about it: "Astrophysicists have been at a loss to account for its extremely strong radiation, and it is tempting to suppose that the energy is coming from the galaxy's capture of a gob of anti-matter coming from an anti-galaxy." It is surely a much likelier solution that thermonuclear processes are being engendered in this successful cosmic "Zeta."

The success of two more recent predictions—that the temperature in solar atmospheric electrical discharges must reach over 100,000,000° K, and that spiral nebulae should exist on a stellar scale—have been described in two earlier notes (1b, d).

The main purpose of the present note is to deal further with the subject of the second of these successful predictions, namely the forms of some of the planetary or spiral stellar nebulae, and to link them up with the very similar forms observed on a galactic scale.

2. BARRED SPIRAL NEBULAE

Barred spiral galaxies are of three kinds, as was shown by Hubble's original classification of the extra-galactic nebulae, which is reproduced in Fig. 1. There is obviously an essential difference in structure be-

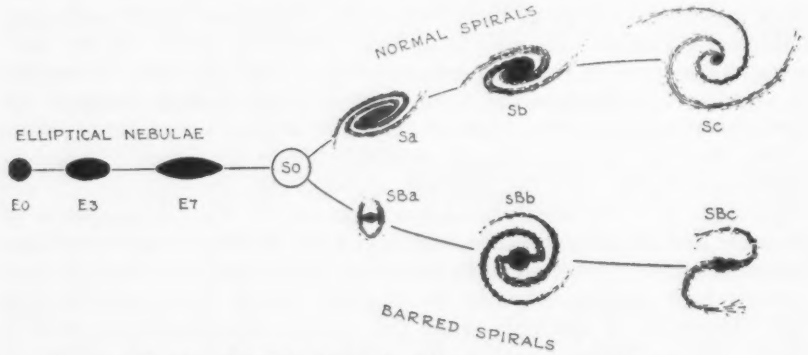


FIG. 1. Hubble's scheme of extragalactic nebular evolution.

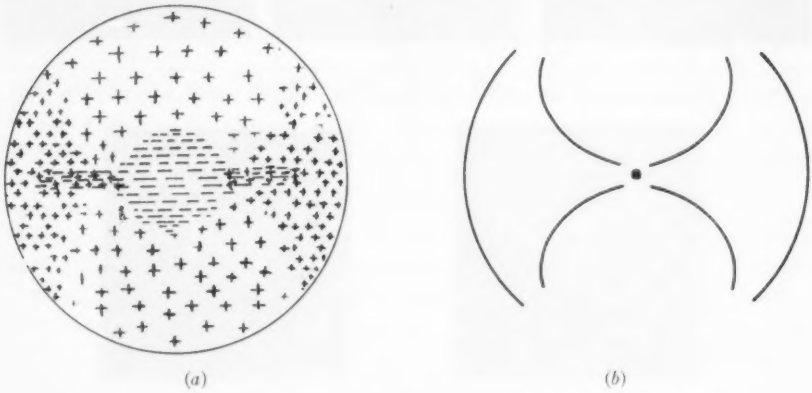
tween the first type, SBa, and the two later types. As regards the latter, they probably differ only in the moment at which one discharge deviated from the radial direction.

Incidentally, a suggestion was put forward in an earlier report (1e) to account for the existence of the two major spiral arms in the galaxies.

Given spherical symmetry of charge distribution, or rather circular symmetry about one axis, there would appear to be no reason why both

discharges should not remain radial, and in the same straight line. However, if one is deviated from its original radial direction, for example, by a concentration of space charge, then the resulting distortion of the electrostatic field at the advancing tip of the other discharge, will be such as to make it, too, deviate from its original direction, and the deviation will be in the opposite direction to that of the first discharge channel. So the spiralling process will be initiated in the two arms of the nebula.

If, however, this deviation from the radial direction does not occur in either discharge—and this happens more frequently on a stellar, than on a galactic scale, which is perhaps not surprising when one considers the size factor—then a new situation arises. This is illustrated diagrammatically in Fig. 2*a*. As in the lightning flash or the long spark



(*a*) (*b*)

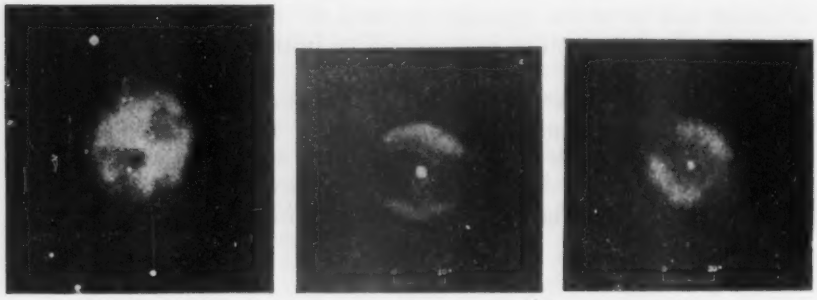
FIG. 2. Diagram illustrating the formation of nebulae of Type SBa.

discharge (1f), the propagation of these "leader strokes" represents at least a partial short circuit of the pre-existing radial electric field. Large field concentrations are therefore built up at the advancing tips of the discharges, causing considerable concentrations of space charge around them. When these advancing tips approach the confines of the galactic or stellar atmospheres the field in the radial direction will be considerably reduced, as compared with the lateral field surrounding the tip. The discharge cannot proceed far beyond the original spherical or ellipsoidal bounds of the atmosphere, and as the confining self-magnetic field due to the current in the discharge will be considerably reduced as compared with that which confines the inner regions of the discharge, lateral breakdown will be possible, to provide an umbrella-like discharge formation at the ends of each discharge channel.

The result will be a nebular form represented by the diagram in Fig. 2*b*. On the *galactic* scale, this will be seen to explain Hubble's

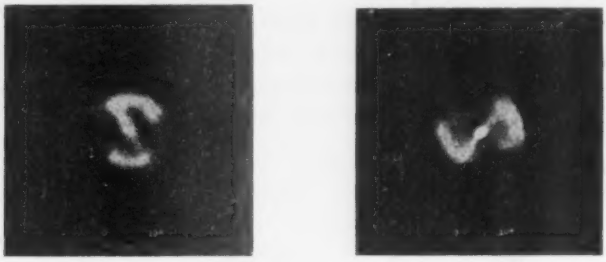
Type SBa, which, as has been said, differs markedly in structure from his Types SBb and SBc.

Examples of this same type of nebular formation on a *stellar* scale are shown in the photographs of NGC 3587, 6058 and 6563 in Fig. 3.



(*a*) (*b*) (*c*)

FIG. 3. Photographs of *stellar* nebulae of Type SBa: NGC 3587, 6058, 6563 (Curtis, **2b**).



(*a*) (*b*)

FIG. 4. Photographs of *stellar* nebulae of Type SBb: NGC 2452, 6778 (Curtis, **2b**).

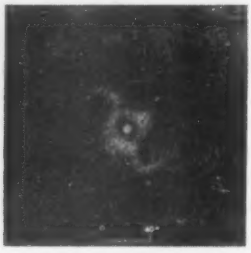


FIG. 5. Photograph of *stellar* nebula of Type SBc: NGC 4361 (Curtis, **2b**).

Stellar nebulae corresponding to Hubble's Type SBb are shown in Fig. 4, NGC 2452 and 6778, while NGC 4361, Fig. 5, is an example on a stellar scale of Hubble's Type SBc. All these stellar, or planetary, nebulae are taken from Curtis's original paper (**2b**).

3. GAS MOVEMENTS IN BARRED STELLAR AND GALACTIC SPIRAL NEBULAE

It was shown in Sections 2 to 4 of the second of the earlier papers already referred to (**1b, g**) that the discharge theory affords for the first time an explanation of the gas movements observed in these barred spiral nebulae on both the stellar (**4**) and galactic (**5**) scales.

4. IRREGULAR NEBULAE

In the foregoing sections it has been taken for granted, as will fairly obviously be true, that the rotational diametral plane will also be the plane in which the electric field is a maximum, so that breakdown will occur in, and be fairly closely confined to that plane, so that the final form in Type SBa, for example, will be more akin to a section through an umbrella, in what were originally ellipsoidal galaxies. However, if the residual angular momentum of the gas comprising the galaxy is relatively very small, then there will be no diametral rotational plane and no plane in which the electric field will be markedly increased. There will thus be no preferred plane in which the discharges will occur. Their directions of propagation will therefore be governed by random concentrations of space charge. On the electrical discharge theory of galactic evolution it is therefore not surprising that there exists a small proportion—of the order of 1 per cent—of galaxies whose form is quite irregular and shows no sign of the normal spiral structure. Apart from this difference in form, however, these galaxies appear similar to the spirals, as for example in the concentration of the gas and dust along the irregular channels, and as regards their stellar contents. Population I stars occur in the irregular arms, as they do in the spiral arms of the more normal galaxies, and these arms also are threaded through a general background of older Population II stars.

This similarity of the stellar contents of arms and background, respectively, in both irregular and spiral galaxies, is highly significant from the point of view of the nature of the evolutionary processes involved. For it does indicate that both types have been formed by the same process, as the discharge theory suggests, and *therefore rules out rotation as the prime cause*, which has been the basis of most attempts hitherto made to explain the origin of the spiral arms.

5. STELLAR POPULATIONS I AND II

As was indicated in the earlier of the two previous papers (**1a**), the discharge theory offers an explanation for the existence of two stellar populations in those galaxies in which electrical breakdown of the general atmospheric electric field has at some time occurred. One population of older stars will be formed throughout the whole atmosphere contemporaneously with the building up of the electric field. Thus, it is suggested that these constitute Population II.

The discharges when they occur will have little effect on these mas-

sive stars, but they do have considerable effect on the distribution of gas and dust. By the magnetic pinch effect this is gathered to the discharge channels, in which the density is thus considerably increased. In these regions of greatly increased density of gas and dust, a second population of stars will be formed relatively quickly. This is the new Population I stars, which are found only in those galaxies in which the gas has been collected along discharge channels—the spiral and irregular nebulae. They do not occur in the E-Types, in which the discharges have yet to occur.

There is one piece of evidence which strongly supports this theory of the origin of the two stellar populations. Despite the fact that Population II stars are known to be much older than are those of Population I, the proportion of heavy atoms in them is only about one tenth of the corresponding proportion observed in Population I stars. Such a qualitative difference would appear to be the reverse of what it is to be expected if change in the atomic population derived entirely from thermonuclear reactions in the stellar nucleus. However, it *is* to be expected on the discharge theory, since the difference between *all* the gas which goes to the formation of Population I stars, and that which originally went to the formation of Population II stars, is that the former has been subjected to a "thermonuclear" electrical discharge, in which the gas was raised to a temperature of about 400,000,000° K, for a time of the order of tens or hundreds of millions of years.

In order to change the initial proportion of 0.003 heavy atoms of Population II stars into the observed proportion of 0.03 in Population I stars by such a discharge, it is estimated that a value of n of the order of 10^6 would be required. Since the average density in galactic atmospheres is about 1 atom per cm^3, this would mean that there is a contraction in two dimensions by a factor of about 10^3 during the formation of the spiral arms. This is not necessarily excessive when one considers the effect of the magnetic pinch effect in increasing the density, but it is an aspect of the theory on which comments would be welcomed from those who are more expert in the field of thermonuclear reactions than is the writer.

6. INTERGALACTIC EFFECTS

It was shown in the two earlier accounts (**1a**, **b**) that the electromagnetic forces involved in these cosmic electrical discharges far outweigh those due to gravitation. This is observed, as was pointed out, in the arc-welding process, in the lightning discharge, and in the gas movements in the atmospheres of the long-period variable stars. It will also account for some of the observed intergalactic effects, which have proved inexplicable on existing theories. For example, at the International Astronomical Union's Third Symposium on Cosmical Gas Dynamics held at Cambridge, Mass., in 1957, one of the speakers was

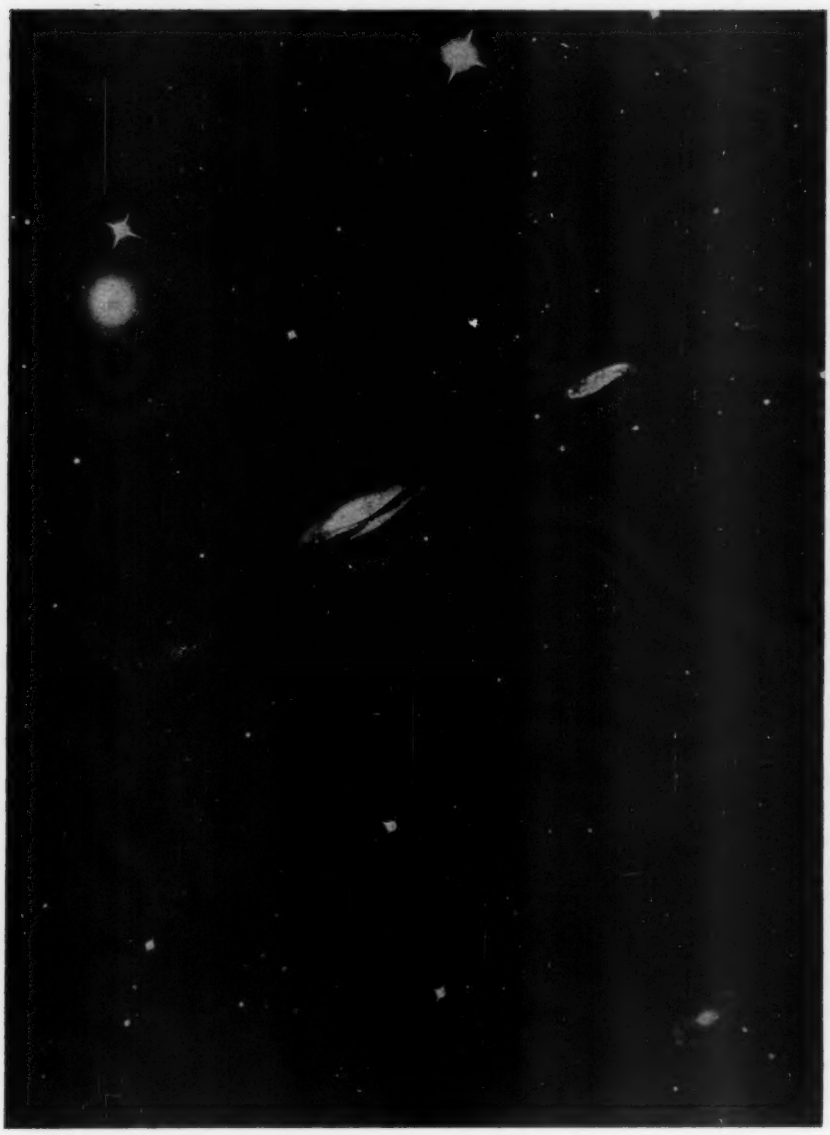


FIG. 6. Interacting galaxies (NGC 3187 and NGC 3190).

asked to comment on the nonplaneness of the galaxy, which he had referred to as a possible tidal effect, and whether an explanation could be given in terms of gravitational interaction with the Small and Large Magellanic Clouds. He replied that ". . . the distortion observed . . . is too large by about two orders of magnitude to be explained by gravitational effects. But really I am not surprised. We see such enormous distortions in many galaxies, and bridges between galaxies, and also more fancy things which cannot possibly be explained by gravitation, neither in order of magnitude nor even qualitatively in shape."[3]

Figure 6 shows one of the "fancy things" which the speaker probably had in mind, for the effect of the upper on the lower galaxy is obviously at right angles to any possible gravitational effects. However, at least "qualitatively in shape," it is certainly in accord with what is to be expected on the discharge theory. For, if large currents flowed round the spiral arms or discharge channels of the large upper galaxy, while the discharges were also in progress in the smaller lower galaxy, then the currents in the latter would be constrained to flow along the magnetic field due to the former, and account for the right angled turns taken by the discharges in the lower galaxy.

7. COSMOLOGICAL THEORIES

The theory has a contribution to make to the cosmological discussion as to whether there was a process analogous to creation, followed by one of universal evolution, or whether creation of matter is a continuous process throughout the universe. On the discharge theory there is obviously a process of universal evolution in which a major role is played by the magnetic pinch effect of the cosmic discharges, which leads to concentration of atmospheric gas and dust of galactic and stellar atmospheres, and facilitates its further aggregation into stars and planets, respectively.

It is to be expected that, as is actually observed, the aggregation of matter of the original universal atmosphere would result in galaxies of different sizes, just as on the lower scale of aggregation stars of very different sizes are formed. In these galaxies there will therefore be considerable variation from galaxy to galaxy in the factors on which the generation of atmospheric electric fields depend: for example, gravitational force, gas density and density gradient, gas velocities, temperatures and temperature gradients.

This problem of the build-up of these atmospheric electric fields cannot yet be dealt with at all satisfactorily and it may be recalled that the much-studied question of the cause and rate of charge generation and separation in thunderclouds is still unsolved, though it has been the subject of investigation since Franklin's day. Quite recently, after two hundred years of researches, entirely new conceptions were introduced

[3] *Rev. Mod. Phys.*, Vol. 30, p. 925 (1958).

into the study of these terrestrial processes (6) which their originators believe are the only ones capable of giving a satisfactory quantitative agreement with observation. It may be that somewhat analogous processes are operative in all cosmic dust-filled atmospheres, though it seemed to the writer highly probable that charging of dust particles by asymmetrical impacts would explain the phenomena, as it does in terrestrial dust and sand storms (1h).

Since the times involved in electric field-generation in terrestrial thunderstorms are of the order of 10^2 seconds, in stellar atmospheres, of the order of 10^7–10^8 seconds (1a), and in galactic atmospheres would appear to be of the order of 10^9 years, we may conclude that these times will be less in smaller galaxies than in larger ones. This leads to the conclusion that the discharges will occur earlier in smaller galaxies, and that the processes of galactic evolution generally will be speeded up therein, in other words, the most highly developed spirals of Hubble's Types Sc and SBc, should occur in the smallest galaxies. Type Sb galaxies should on an average be larger, and Type Sa, in which the discharges have only relatively recently occurred, and in which the spiral arms are consequently less well developed, should be larger still. Largest of all, on this view, should be the globular and elliptical galaxies, for in them the atmospheric electric field has still not reached the breakdown value. *We thus expect an evolutionary life in any one galaxy in the direction of Hubble's scheme, that is, from left to right in Fig. 1*, but considering all galaxies, the latest type spirals, Sc, will be associated with the smallest galaxies, and *there will be an increase in average size in the sequence* $Sc \rightarrow Sb \rightarrow Sa \rightarrow E$.

This "size-type" sequence is actually observed, in accordance with these deductions from the discharge theory. However, it is usually misinterpreted as representing an evolutionary sequence in all *individual galaxies*, that is, that galaxies grow in size throughout their lives, and at the same time evolve along the evolutionary sequency Sc→Sb→Sa→E. This naturally requires the initial postulate that galaxies somehow start with well-defined spiral, or barred spiral, or irregular, arms, formed by some quite unknown process, *not rotation*, and that these gradually disperse with time, as the galaxy also grows considerably in size. It is now suggested that the discharge theory offers a preferable and logically consistent alternative to this rather nebulous view of galactic evolution, and one which is based on physical principles which are well observed, if not always thoroughly understood, for example, so far as the field building processes are concerned.

The existing view appears to derive mainly from the observation that galaxies of Type E are by far the largest, contain the oldest stars, and are relatively free from gas and dust. The first and second of these observations are obviously quite in keeping with the view now put forward, while the third may be accounted for by the contrast between the

effects of the considerable increase in density of gas and dust effected by the discharge during the formation of the spiral or irregular arms, in those galaxies in which the discharges have occurred, and the relatively negligible absorption effects in the absence of this concentration.

The discharge theory would also afford an explanation for two of Hubble's main comments on his scheme of galactic evolution. In the first place the occurrence of the discharges would account for the "cataclysmic action" which he considered necessary to account for the change from Type E7 to Type Sa at SO—"this critical point in the evolutional development of nebulae."[4] Secondly it would explain why "Sa spirals are always found with arms fully developed" (**1c**, p. 47). The reason for this will be understood when the difficulty experienced in photographing the "jet" or discharge channel in the radio-source, Virgo A, NGC 4486, is called to mind. The discharge occurs deep in the dusty atmosphere, and it is only by careful filtering of the light that the "jet" could be detected at Mount Wilson and Palomar Observatories (**1a**). When the aggregation of the matter onto the discharge channel at last becomes apparent, the discharge is long past, and its channel becomes apparent as a whole, with the arms fully developed. This is the view of galactic evolution first put forward many years ago (**1c**), to which subsequent events, such as the discoveries of radio-astronomy and galactic radio-sources, of the existence of two stellar populations, of stellar spiral nebulae, and of temperatures of a hundred million degrees in cosmic atmospheres, have continued to contribute considerable additional support.

8. ENERGY OF COSMIC RADIO SOURCES[5]

One of the *many* major difficulties met by existing astrophysical theories is that of explaining the amount of energy radiated by extragalactic radio sources. Dire explanations have been offered, such as the collision of galaxies with "gobs of anti-matter from anti-galaxies" (**3**), or stellar explosions being triggered off by stellar explosions (**8**) in gigantic galactic "Brock's benefit nights." Even the relatively sober suggestion that some sources are collisions between galaxies requires the assumption that somehow the necessary magnetic fields and relativistic electrons are generated during the collision, by some unknown physical process or processes.

In contrast, the energy is easily accounted for on the discharge theory. It was indicated in Section 5 that the effect of the "thermonuclear" discharges during the formation of the spiral arms is to convert the proportion of 0.003 heavy atoms in the primordial gas of a galaxy, which goes to the formation of Population II stars, into the 0.03 observed in the stars of Population I. In order to estimate the

[4] "The Realm of the Nebulae," p. 46.

[5] This section was added to the paper on July 7, 1961.

order of magnitude of the energy liberated during this change we may assume that .03 of the hydrogen becomes helium, and in so doing about 1 percent of the mass involved is radiated as energy. The total mass of the average galaxy is that equivalent to about 10^{10} suns, or 10^{43} gm. The mass radiated is therefore of the order of 10^{39} gm. The total energy radiated will therefore be about 10^{60} ergs of which part only will be in the range of radio wavelengths. This theoretical estimate agrees quite well with the value of 10^{58} ergs quoted (**8**) for the total energy radiated during the life of a radio galaxy. This is based on the energy radiated from NGC 4486 in which the discharges are in an early stage of development.

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SOME CONSEQUENCES OF A LINEAR VECTOR THEORY OF INERTIAL FIELDS

BY

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ABSTRACT

The existence of a static field associated with rotating mass is assumed. This field combines with the ordinary gravitational field so as to form the linear, Lorentz invariant structure of "inertial fields." It is shown that by pursuing the consequences of this postulate one can qualitatively predict several general relativistic effects while also accommodating all special relativistic effects. By providing a link between local dynamic events and the rest of matter over all of space, the theory of inertial fields leads to a logically coherent model of inertial force fields and suggests an approach to the realization of Mach's program. A rotary motion equivalence principle is obtained.

I. INTRODUCTION

The ever increasing complexity of general relativistic formalism strongly warrants the complete study of simpler approaches to the analysis of gravitational phenomena. In search for such an approach, a review of general relativistic predictions was undertaken.

It soon became clear that by postulating the existence of a static field associated with rotating matter, several predictions based on the complete structure of relativity can be approximated through the use of Maxwell type field equations. Beyond this initial success, our studies lead to a logically coherent model of inertial force fields embodying Mach's Principle.

It was found quite early in our studies that the assumption of the existence of a fourth force field, beyond electric, magnetic and gravitational fields (neglecting nuclear force fields) was in itself not new. Our *S*-field is conceptually identical with Hund's axial gravitational vector field (**1**)[2] (1948), Sciama's gravomagnetic field (**2**) (1953), Mertz' "movetnik" field (**3**) (1954), Costa de Beauregard's "champ gravitational de spin" (**4**) (1958) and Forward's "protational field" (**5**) (1961).

It is felt, however, that none of these authors proceeded sufficiently far to obtain the complete benefit of the assumption.

In the present paper we attempt to describe the outlines of a field theory beginning from first principles. Then we investigate the predictions of the theory, without claiming to offer a replacement of or even a new approach to the more complete structures of theoretical physics.

The relations of this paper are written in Gaussian c.g.s. units.

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[1] Senior Staff Member, GPL Division, General Precision, Inc., Pleasantville, N. Y.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

II. BASIC PRINCIPLES

1. Gravitational Fields

The magnitude and direction of the force exerted by a gravitational field on a test particle of unit mass can be used to measure the magnitude and direction of the gravitational field. *Gravitational field intensity* then can be represented by[3]

$$\mathbf{T} = -\frac{\mathbf{F}}{m}, \qquad [T] \equiv LT^{-2} \tag{1}$$

where the negative sign was inserted for later advantage.[4]

Gravitational field intensity can be conveniently described by *gravitational flux* which is pictured as emanating from mass M and extending over all space. The total flux emanating from the source M is $4\pi M$. This quantity is related to *gravitational flux density* $\mathfrak{y}$ by

$$4\pi M = \iint \mathfrak{y} \cdot d\mathbf{a}. \qquad [\mu] \equiv ML^{-2}. \tag{2}$$

Gravitational flux density follows the direction of gravitational field and is at every point in space directly proportional to the intensity of the gravitational field, so that

$$\mathbf{T} = \frac{1}{\alpha}\mathfrak{y}, \qquad [\alpha] \equiv ML^{-3}T^{2} \tag{3}$$

for the simple case of isotropic space.

We call constant α *matter permittivity*.

If the integration indicated by Eq. 2 is performed over the surface of a sphere of radius R, we obtain

$$\mathfrak{y} = \frac{M}{R^{2}}\mathbf{R}. \tag{4}$$

Eliminating $\mathbf{T}$ from Eqs. 1 and 3 and inserting Eq. 4 for $\mathfrak{y}$ we get

$$\mathbf{F} = -G\frac{Mm}{R^{3}}\mathbf{R}. \tag{5}$$

The force $\mathbf{F}$ is the force of gravity; the reciprocal matter permittivity

$$\frac{1}{\alpha} = G, \qquad [G] \equiv M^{-1}L^{3}T^{-2} \tag{6}$$

is the *universal constant of gravitation*.

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[3] For a list of symbols used in the study of inertial fields, see the Appendix.

[4] The capital letter T is used in the present paper to represent gravitational field intensity in the equations as well as "time" in the expressions of dimensions. The quantities, however, are sufficiently different in significance and sufficiently separate in the formal relations so as to preclude confusion.

It is readily shown by arguments identical to those used in electrostatics that *matter density* ρ and gravitational flux density $\mathfrak{y}$ are related by

$$\nabla \cdot \mathfrak{y} = 4\pi\rho. \qquad [\rho] \equiv ML^{-3}. \tag{7}$$

2. A Model of Rotating Mass

We propose to construct a model of rotating mass by using the concept of *matter current.* Matter current can be defined as mass crossing an area per unit time

$$\mathfrak{M} = \frac{m}{t}. \qquad [\mathfrak{M}] \equiv MT^{-1}. \tag{8}$$

A circulating matter current can be called a *matter loop.* In our model of rotating mass, an orbiting particle can be thought of as constituting a matter loop. In the case of a rotating body, the matter loop is the mass of the body circulating about the axis of rotation at the distance of radius of gyration.

We postulate the existence of a dipole moment **J** associated with a matter loop. The magnitude and direction of this dipole moment is defined by

$$\mathbf{J} = \beta\mathfrak{M}(\mathbf{area}). \qquad [J] \equiv L^3T^{-1}. \tag{9}$$

In words, $|J|$ is directly proportional to the magnitude of the circulating matter current and to the area of the matter loop. We call the constant β *matter permeability.* It is shown in Section 4 that the dimension of matter permeability is $M^{-1}L$. We call the quantity **J** an "*S-dipole moment.*"

The *S*-dipole moment can be thought of as the product of a length **l** and a fictitious quantity m^* so that

$$\mathbf{J} = m^*\mathbf{l}. \qquad [m^*] \equiv L^2T^{-1}. \tag{10}$$

The quantity m^* can be called an "*S*-mass."

We can conceive of two "*S-poles*" associated with a matter loop. We designate these two poles by the letters *A* and *B* and refer to them as "austral" and "boreal" poles. Their positions can be determined by a system based on the right-hand convention (Fig. 1).

Finally, we postulate the existence of an "*S-field*" associated with the *S*-dipole and conceive of this field as the fourth field of a group that already includes electric, magnetic and gravitational fields.[5]

[5] It is clear that a particle of intrinsic spin, itself being the case of a special matter loop, possesses an intrinsic *S*-field. It follows that a "permanent magnet" is also a "permanent *S*-field source."

3. Nomenclature

The first manifestations of the force field postulated in Section II-2 were calculated for the case of a spinning body. The name "spin field" suggested itself, together with other quantities not yet introduced, such as "spin flux density" and "spin field strength." It was soon realized, however, that such fields, while also associated with rotating bodies and with spin particles, are more general in their nature. The letter S and the name "S-field" were, however, retained.[6]

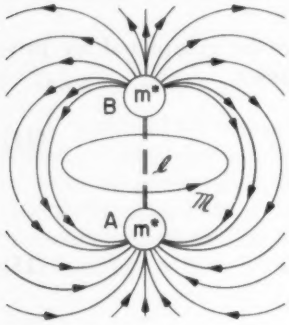

FIG. 1. Parameters of the S-field of a matter loop.

FIG. 2. Displacement momentum density appearing outside the confines of the aggregate of moving particles.

4. S-Fields

The strength and direction of an S-field can be measured by the magnitude and direction of the force exerted by the field on a unit S-mass. *S-field intensity* is represented by

$$\mathbf{S} = -\frac{\mathbf{F}}{m^*}, \qquad [s] \equiv ML^{-1}T^{-1} \tag{11}$$

where the negative sign was inserted for later advantage.

S-field intensity can be conveniently described by *S-flux* which is pictured as emanating from S-mass m^* at the boreal pole and terminating on the austral pole. The integral of S-flux density $\mathbf{S}$ taken over any closed surface is identically zero

$$\int\int \mathbf{S} \cdot d\mathbf{a} = 0, \qquad [\mathrm{S}] \equiv T^{-1} \tag{12}$$

[6] At the time this article goes to press, we have adopted the term *spinetic* for the description of S-phenomena. This term appears to be phonetically descriptive and well suited for the generation of more complex terms; to wit, *spinetic dipole* for "S-dipole," *spinetic susceptibility* for "S-susceptibility" or *permanent spinet* for a "permanent S-field source."

because of the solenoidal nature of the field.[7] *S*-flux density follows the direction of *S*-field and is at every point in space directly proportional to the strength of the field, so that

$$\boldsymbol{S} = \frac{1}{\beta}\mathbf{S}. \qquad [\beta] \equiv M^{-1}L \tag{13}$$

Matter permeability β here appears as a general measure of the ability of circulating matter current to develop *S*-poles (exhibit the presence of *S*-mass) and produce *S*-fields. It is in this role that β appears in Eq. 13 as well as in Eq. 9.

The set of equations involving *S*-mass can be completed by proposing a Coulomb's law type relation for *S*-masses

$$\mathbf{F} = -K\frac{m_1^* m_2^*}{R^3}\mathbf{R}. \tag{14}$$

We call the reciprocal of matter permeability

$$\frac{1}{\beta} = K, \qquad [K] \equiv ML^{-1} \tag{15}$$

the *universal S-field constant.*

We note that because of the "sourceless" or solenoidal nature of *S*-fields

$$\nabla\cdot\mathbf{S} = \beta\nabla\cdot\boldsymbol{S} = 0. \tag{16}$$

The negative sign in Eqs. 1 and 11 were necessary to make our notation consistent with that used in electrodynamics. In our system masses of similar sign and *S*-poles of similar designation attract, while masses of opposite sign and *S*-poles of opposite designation repel. It follows that the flux lines, as anticipated above, originate on *B* poles and terminate on *A* poles and that the unit *S*-mass used in Eq. 11 to determine the direction and magnitude of the *S*-field must be a boreal or *B* pole.

5. *Flow of Matter and Displacement Momentum Density*

Consider a matter current flowing past an observer. For heuristic reasons let us choose the example of an aggregate of particles translating in a pipe. Let this pipe be bent around so as to form an almost complete toroid (Fig. 2). Present theories will account for the dynamical processes involved in the matter flow in terms of gravitational and "inertial"[8] effects. We will assume, however, that in addition to all

[7] Note that **S** and *S* are the symbols used to represent spinetic flux density, while (italic) ***S*** and $\mathbb{S}$ represent spinetic field intensity.

[8] The use of quotation marks for "inertial" is explained in Section III–15*a*.

dynamic processes that are involved in the phenomenon of the matter current, the flow of particles represented by momentum density **P** in the figure also produces an additional effect outside the confines of the aggregate of the particles by setting up a *displacement momentum density* ***P***.

The quantity that suggests itself as suitable for being identified with displacement momentum density[9] is the time rate of change of gravitational flux density $\mathfrak{y}$ of Eq. 2 so that

$$\boldsymbol{P} = \frac{\partial \mathfrak{y}}{\partial t}. \qquad [P] \equiv ML^{-2}T^{-1} \tag{17}$$

6. Inertial Fields

A review of what was said indicates that angular or linear momenta appear to have the attribute of being able to set up fields outside the confines of ponderable matter. Linear momentum is related to displacement momentum density and to gravitational fields; angular momentum is related to *S*-fields. We propose to call gravitational fields and *S*-fields together by the generic name of *inertial fields*.

The parameters of inertial fields can be suitably arranged in two groups:

(*a*) The gravitational field components of gravitational field intensity **T**, and gravitational flux density $\mathfrak{y}$; and
(*b*) the *S*-field components of *S*-field intensity ***S*** and *S*-flux density **S**.

Other quantities we have introduced include momentum density **P**, displacement momentum density ***P***, matter density ρ, matter permittivity α, and matter permeability β.

The equations that connect the vector quantities with the constitution of matter, or the "constitutive equations" of inertial fields can be collected from Sections II-1 and II-4. They are

$$\mathbf{T} = \frac{1}{\alpha}\,\mathfrak{y} \tag{3}$$

$$\boldsymbol{S} = \frac{1}{\beta}\,\mathbf{S}. \tag{13}$$

We propose a set of Maxwell type differential equations for the description of inertial fields, identical with those proposed by Mertz (3) and resembling those of Milner (6).

[9] It is noted that displacement momentum density can also be considered a "mass current density." The former name, however, appears to be more descriptive and consistent with the substance of this paper.

Two of these equations (7 and 16) were already written. A third one follows when Ampère's circuital law is applied to inertial fields with Eq. 17 added. The fourth one is Faraday's law of induction. The field equations are

$$\text{I} \quad \nabla \cdot \mathfrak{y} = 4\pi\rho \tag{7}$$

$$\text{II} \quad \nabla \times \boldsymbol{S} = 4\pi\mathbf{P} + \frac{\partial \mathfrak{y}}{\partial t} \tag{18}$$

$$\text{III} \quad \nabla \cdot \mathbf{S} = 0 \tag{16}$$

$$\text{IV} \quad \nabla \times \mathbf{T} = -\frac{\partial \mathbf{S}}{\partial t}. \tag{19}$$

Equation I indicates that gravitational flux can originate and terminate on matter in bulk described by volumetric density ρ. The direction and magnitude of the gravitational field are determined at each point in space by the test represented by Eq. 1.

It is not necessary for the discussion of inertial fields to assume the existence of mass of a sign opposite to the sign that appears to be common in our experience. If the existence of negative mass is postulated, however, it forms an organic part of the system, as discussed in Section III-15.

Taking the divergence of both sides of Eq. 18, we get

$$\nabla \cdot \mathbf{P} + \frac{\partial \rho}{\partial t} = 0, \tag{20}$$

the equation of continuity of inertial fields.

Equation II is Ampère's circuital law applied to inertial fields.

Equation III specifies that the *S*-flux density and, for a constant matter permeability, the *S*-field intensity $\boldsymbol{S}$ be solenoidal. This requirement is necessary if *S*-fields are to have vector potential; in turn, if there is to be inertial radiation, vector potential is essential.

Equation IV is an expression of Faraday's law stating that the gravitational field has curl in a region in which the *S*-flux density changes with time.

The equations for inertial fields in free space, that is in the absence of ponderable matter, can be obtained from the field equations as follows

$$\nabla \cdot \mathfrak{y} = 0 \tag{21}$$

$$\nabla \cdot \mathbf{S} = 0 \tag{22}$$

$$\nabla \times \boldsymbol{S} = \alpha \frac{\partial \mathbf{T}}{\partial t} \tag{23}$$

$$\nabla \times \mathbf{T} = -\beta \frac{\partial \mathbf{S}}{\partial t}. \tag{24}$$

The fields $\mathbf{T}$ and $\mathbf{S}$ in the above equations for free space satisfy the wave equation with a wave velocity of

$$\sqrt{\frac{1}{\alpha\beta}} = \sqrt{GK} = v \equiv c. \tag{25}$$

We assume that this velocity is that of the velocity of light. If this assumption corresponds to fact, we obtain for a value of $G = 6.7 \times 10^{-8}$ $\mathrm{gr^{-1}\ cm^3\ sec^{-2}}$, the value of the universal S-field constant $K = 1.35 \times 10^{28}$ $\mathrm{gr\ cm^{-1}}$.

7. The Transformation Laws

It is the property of the Maxwell type field equations that they will seem correct to an observer traveling at constant velocity as well as to an observer at rest, this property being the expression of the Lorentz form-invariance of these equations.

Consider now two coordinate systems with their axes parallel, the primed system moving at velocity v with respect to the unprimed system along the common X axes and without rotation. The field components will transform exactly as they do in electrodynamics (7) and we have

$$S_x' = S_x, \tag{26}$$

$$S_y' = \left(1 - \frac{v_x^2}{c^2}\right)^{-1/2} \left(S_y + \frac{1}{\eta}\frac{v_x}{c} T_z\right) \approx S_y + \frac{1}{G} v_x T_z, \tag{27}$$

$$S_z' = \left(1 - \frac{v_x^2}{c^2}\right)^{-1/2} \left(S_z - \frac{1}{\eta}\frac{v_x}{c} T_y\right) \approx S_z - \frac{1}{G} v_x T_y, \tag{28}$$

$$T_x' = T_x \tag{29}$$

$$T_y' = \left(1 - \frac{v_x^2}{c^2}\right)^{-1/2} \left(T_y - \eta \frac{v_x}{c} S_z\right) \approx T_y - \frac{G}{c^2} v_x S_z, \tag{30}$$

$$T_z' = \left(1 - \frac{v_x^2}{c^2}\right)^{-1/2} \left(T_z + \eta \frac{v_x}{c} S_y\right) \approx T_z + \frac{G}{c^2} v_x S_y, \tag{31}$$

where the quantity η is the *intrinsic impedance of space* for inertial waves, and

$$\eta = \sqrt{\frac{\text{matter permeability}}{\text{matter permittivity}}} = \sqrt{\frac{\beta}{\alpha}} = \sqrt{\frac{G}{K}} = \frac{G}{c}. \quad [\eta] \equiv M^{-1}L^2T^{-1} \tag{32}$$

It is clear that the magnitudes of the field components, as experienced by the different observers, vary. For example, what appears to be a gravitational field for an observer in the stationary (unprimed) system, will appear as a gravitational field *and* an S-field for an observer at rest in the translating coordinate system.

8. Inertial Lorentz Forces

The transformation Eqs. 26–31 can be stated vectorially, neglecting the special relativistic correction, as

$$\mathbf{T}' = \mathbf{T} - \frac{G}{c^2}\boldsymbol{S} \times \mathbf{v}, \tag{33}$$

and

$$\boldsymbol{S}' = \boldsymbol{S} - \frac{1}{G}\mathbf{v} \times \mathbf{T}. \tag{34}$$

It is now recalled that both $\mathbf{T}$ and $\boldsymbol{S}$ represent force fields. Using Eqs. 33 and 34 one can write the vector equations for inertial Lorentz forces, remembering the basic relation (Eq. 1). We have for the equation of motion for velocities small compared with the speed of light

$$\frac{d\mathbf{p}}{dt} = -m\mathbf{T} + m\frac{G}{c^2}\boldsymbol{S} \times \mathbf{v}. \tag{35}$$

9. Inertial Larmor Precession

Figure 3 depicts the direction of the S-field in the equatorial plane and along the axis of a spinning body, according to the convention established in Fig. 1. It is clear that a test S-dipole, if placed in the S-field of the body will tend to align itself opposite to the direction of the S-field. The magnitude of the torque acting on the test S-dipole is

$$|\text{Torque}| = \boldsymbol{S} \times \mathbf{J} = J \cdot \mathfrak{s} \sin\theta \tag{36}$$

from classical mechanical considerations. A study of the directions of the vector quantities discloses that the sense of the ensuing precession of the test particle will be the same as the sense of rotation of the central body if the particle is placed along the polar axis of the rotating body; if the particle is in the equatorial plane, the ensuing precession will have a sense opposite to that of the rotation of the central body.

For a centrally symmetrical gravitational field, such as the example given, and a weak S-field one can obtain the frequency of the particle's precession by the Larmor theorem. This frequency is

$$\boldsymbol{\Omega} = \psi\boldsymbol{S}. \qquad [\psi] \equiv M^{-1}L \tag{37}$$

The constant ψ is the ratio of the S-dipole moment of the particle to its angular momentum and can be called an *S-gyric ratio*. The value of this constant can be readily calculated for an orbiting particle.

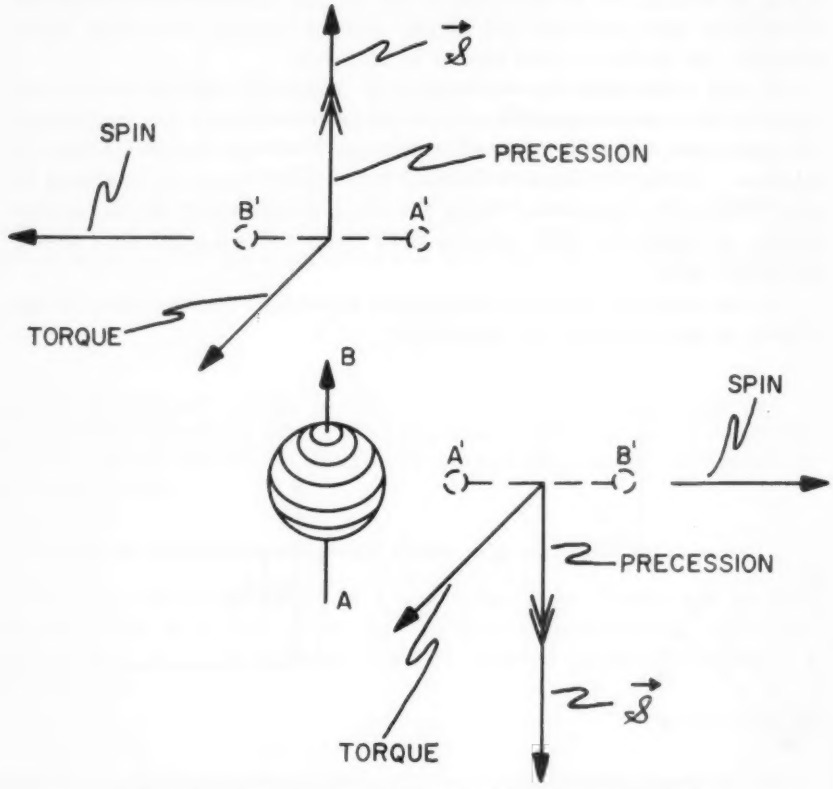

FIG. 3. Inertial Larmor precession in the S-field of a rotating body.

The S-dipole moment of a particle of mass m orbiting along a circle of radius k can be obtained from Eq. 9 as

$$|\mathbf{J}| = \beta \mathfrak{M}(\text{area}) = \beta m \frac{\omega}{2\pi} k^2 \pi = \tfrac{1}{2}\beta I \omega, \tag{38}$$

where I is the moment of inertia. We have

$$\psi_{\text{orbit}} = \frac{J}{I\omega} = \frac{G}{2c^2} \tag{39}$$

where β was replaced by G/c^2 from Eq. 25.

10. A Brief Review

In the prior sections we pursued some of the consequences of our assumption of the existence of *S*-fields. It was shown that inertial fields, as defined, can be detected by the inertial Lorentz forces acting on translating spin particles and by the inertial Larmor precession these particles can perform when placed in an *S*-field.

It was noted that the covariance of Maxwell's equations with respect to the Lorentz transformation takes into account the uniformity of space-time, that is, it permits passage from one inertial frame to another. Thus, the laws of inertial fields, since they are assumed to obey Maxwell's equations, fulfill the basic requirement of the special theory of relativity that natural laws must be expressed in Lorentz invariant form.

In the following sections some of the immediate consequences of the theory of inertial fields are discussed.

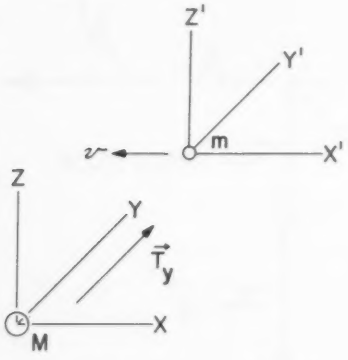

FIG. 4. Planetary coordinates.

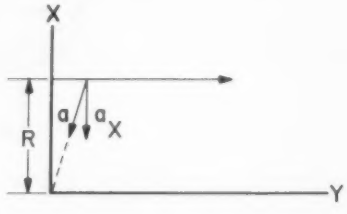

FIG. 5. The orbit of photon passing a large body.

III. IMMEDIATE CONSEQUENCES

1. Planetary Orbits

Consider a coordinate system with the sun at its origin, fixed in the framework of the Universe: that is, in the framework of the extragalactic nebulae. Let another, (primed) coordinate system be attached to an orbiting planet. We can consider, for a brief enough period, the primed coordinate system translating with its X' axis parallel with the X axis of the stationary system. It is assumed that the sun does not rotate and that the only gravitational field component of concern is T_y (Fig. 4).

The only transformation equations that do not vanish are

$$T_y' \approx T_y, \tag{30-1}$$

and

$$\mathcal{S}_x' \approx -\frac{1}{G} v_x T_y, \tag{28-1}$$

where the special relativistic corrections were neglected. The first quantity is the Newtonian acceleration. The second quantity is an S-field intensity that should be detectable by an observer stationary in the primed system, through a suitably designed experiment.

If the special relativistic correction is not neglected, one obtains a special relativistic effect, the Sommerfeld precession (7, p. 217). This precession predicts an advance of the perihelion of planetary orbits by

$$\theta \approx \frac{4\pi^2 a^2}{c^2 \tau^2 (1 - e^2)} \tag{40}$$

radians per period τ of the planet. In (40), a is the semi-major axis, e the eccentricity of the orbit. The expression (40) represents one-sixth of the general relativistic prediction for the advance of perihelion of planetary orbits.

2. Cyclotron Frequency in Inertial Fields

The equations of motion of a test mass in an S-field will be isomorphic with those of a charge in a uniform magnetic field. One can immediately write the equation for the "inertial cyclotron frequency" of a particle

$$\Omega = \beta \mathcal{S} \tag{41}$$

radians per second by inspection of the corresponding equation from electrodynamics.

Let such an S-field be generated by the rotation of a large central body, such as the sun. The magnitude of the S-field intensity in the equatorial plane, at a distance r from the center of a homogeneous rotating sphere is

$$|\mathcal{S}_z| = \frac{1}{\beta} \frac{J}{r^3} = \frac{1}{\beta} \frac{\beta I \omega}{2r^3} = \frac{I\omega}{2r^3} \tag{42}$$

in complete analogy with the calculation of magnetic field strength of a magnetic dipole. In (42) I is the moment of inertia, ω is the angular velocity of the central body.

In the field of the spinning body one obtains a cyclotron frequency of

$$\Omega = \frac{G}{c^2}\frac{I\omega}{2r^3} = \frac{1}{5}\frac{GMR^2}{c^2r^3}\omega \text{ radians/second.} \tag{43}$$

This is a rather samll angular velocity which can be expected to appear as a correction term to other, larger angular velocities. We can bring (43) to an astronomically more familiar form by remembering that the Kepplerian period of a planet moving on a circular orbit is

$$\tau = \frac{2\pi r^{3/2}}{\sqrt{GM}} \text{ seconds/revolution,} \tag{44}$$

where M is the mass of the central body. Multiplying (43) by Eq. 44, we obtain

$$\theta = \frac{2\pi}{5}\frac{(GM)^{1/2}}{r^{3/2}}\frac{R^2\omega}{c^2} \text{ radians/revolution.} \tag{45}$$

This equation represents the angular displacement of the radius vector of an orbiting planet per period τ of the planet, caused by the presence of the S-field. If, for planetary orbits of small eccentricity we replace the radius by the approximation

$$r \approx a(1 - e^2), \tag{46}$$

we obtain, after taking into account the direction of the field for a sun that rotates in the same sense as the particle revolves,

$$\theta = -\frac{2\pi}{5}\frac{(GM)^{1/2}}{[a(1 - e^2)]^{3/2}}\frac{\omega R^2}{c^2} \text{ radians/revolution.} \tag{47}$$

This is a negative advance of the radius vector of the planet due to the presence of the S-field, superimposed on any other periodic or secular motion. Expression (47) represents $2\pi/16$th of the advance of the perihelion of planetary orbits due to rotation of the central body, as predicted by general relativity (8).

3. Secular Precession of an Ideal Gyroscope

Consider again a coordinate system, non-rotating with respect to the "fixed stars" and having the earth at its origin and another, primed coordinate system attached to an orbiting satellite (see Fig. 4). Let the angular, orbital velocity of the satellite be ω', the angular velocity of the central body ω radians per second.

The S-field intensity experienced by the moving particle, neglecting the special relativistic correction, can be obtained from (28) and (42).

We have

$$s_z' = s_z - \frac{1}{\eta}\frac{v_x}{c} T_y = -\frac{I\omega}{2r^3} + \frac{c}{G}\frac{r\omega'}{c}\frac{GM}{r} = -\frac{MR^2}{5r^3}\omega + \frac{M}{r}\omega'. \quad (48)$$

The inertial Larmor frequency of a spin particle or macroscopic free gyro as observed by a co-moving observer can be calculated by using (37) and (39) to give

$$\Omega = \frac{1}{2}\frac{GM}{c^2 r}\omega' - \frac{1}{10}\frac{GMR^2}{c^2 r^3}\omega \text{ radians/second.} \quad (49)$$

The corresponding general relativistic expression (9) is

$$\Omega = \frac{3}{2}\frac{GM}{c^2 r}\omega' - \frac{2}{5}\frac{GMR^2}{c^2 r^3}\omega \text{ radians/second.} \quad (50)$$

Let the test particle (laboratory gyroscope) be constrained to remain at rest with respect to the rotating earth, at the equator of the earth. As a consequence, the two radii become identical ($r \equiv R$) and the two angular velocities become identical ($\omega \equiv \omega'$). The nongravitational constraining acceleration has a magnitude equal to the gravitational acceleration but opposite in sign

$$f = -\frac{GM}{R^2}. \quad (51)$$

There will be a resulting Thomas precession of

$$\omega'' = -\frac{fv_x}{2c^2} = \left(-\frac{GM}{R^2}\right)\left(-\frac{R\omega}{2c^2}\right) = \frac{GM}{2Rc^2}\omega \quad (52)$$

radians per second, which is to be added to the inertial Larmor precession. Using now Eq. 49 with the indicated changes, one has

$$\Omega = \left(\frac{GM}{c^2 R} - \frac{1}{10}\frac{GM}{c^2 R}\right)\omega \text{ radians/second.} \quad (53)$$

The corresponding general relativistic expression (9) is

$$\Omega = \left(2\frac{GM}{c^2 R} - \frac{2}{5}\frac{GM}{c^2 R}\right)\omega \text{ radians/second.} \quad (54)$$

It is interesting to note that the appearance of the precessions represented by (50) and (54) are considered genuine consequences of the general theory of relativity by Schiff. Forward (5) has already shown, however, that the second term of (50) can be obtained through an argument resembling those of this paper. The first term in (50) and

presumably the first term of (54), however, are attributed even in Forward's work to the general relativistic curvature of space.

It appears that these first terms can, nevertheless, be partially accounted for if the transformation properties of gravitational and S-fields are properly employed.

4. Deflection of Light Beam near the Sun

Let a photon be considered a particle of vanishing rest mass traveling at a velocity approaching the velocity of light. Let such a photon travel approximately parallel with the Y axis of the coordinate system shown on Fig. 5. The magnitude of the acceleration is

$$\frac{GM}{R^2} \tag{55}$$

pointing along the radius of the massive body. If a_x designates the acceleration parallel with the X axis, we have

$$\frac{a_x}{a} = -\frac{R}{\sqrt{x^2+y^2}}. \tag{56}$$

The velocity of the particle along the X axis at time t is

$$v_x = a_x t = -\frac{GM}{R}\frac{1}{\sqrt{x^2+y^2}}\frac{y}{c}. \tag{57}$$

For values of y much larger than x, (57) becomes

$$v_x \approx -\frac{GM}{Rc}. \tag{58}$$

For small angles we can equate the tangent of the angle to the angle itself, so we find that at a distant point the direction of the flight of the particle will form an angle of

$$\theta' \approx \frac{v_x}{v_y} = \frac{v_x}{c} = -\frac{GM}{Rc^2} \text{ radians} \tag{59}$$

with the X axis. Asymptotically, the total deviation of the path is

$$|\theta| \approx \frac{2GM}{Rc^2} \text{ radians.} \tag{60}$$

This quasi-Newtonian approach, resembling that given by Tolman (10) yields one-half of the bending predicted by the general theory.

The dual nature of light suggests that besides the particle approach, we should also consider the behavior of a light beam as electromagnetic waves in inertial fields. This investigation has not yet been carried out.

5. Additional Deflection of Light Due to Rotation of the Sun

The effect of the rotation of the central body on the path of a photon can be readily calculated by using the approach of Section III-2 for a body of finite rest mass, but going to the limit of zero rest mass.

The inertial cyclotron frequency in an S-field whose magnitude is that observable at the surface of the rotating body that generates it can be obtained from (43) as

$$\Omega = \frac{1}{5}\frac{GM}{Rc^2}\omega \text{ radians/second.} \tag{61}$$

The total angular deviation due to the rotation of the central body, as measured by a non-rotating observer is

$$\theta_1 = \frac{2}{5}\frac{GM}{Rc^2}\theta' \text{ radians,} \tag{62}$$

where θ' is the angle of rotation of the central body during the flight of the photon. For the example of the Sun, for a photon flight time of four sun radii calculation leads to $\theta_1 = 10^{-12}$ radians, a negligibly small quantity.

6. Precession of Photons in Light Beam Passing the Sun

Equation 49 specifies that a spin particle traveling in a gravitational field performs an inertial Larmor precession of the angular frequency

$$\Omega = \frac{1}{2}\frac{GM}{Rc^2}\omega'. \tag{63}$$

Using the coordinate system of Fig. 5, one sees that for photons the angular velocity ω' of Eq. 63 is, to a good approximation,

$$\text{angular velocity} = \text{velocity/radius} \approx \frac{c}{\sqrt{x^2 + y^2}}. \tag{64}$$

During a flight time of $t = y/c$ the photon angular momentum precesses

$$\frac{1}{2}\frac{GM}{Rc^2}\frac{c}{\sqrt{x^2 + y^2}}\frac{y}{c} \approx \frac{1}{2}\frac{GM}{Rc^2} \text{ radians.} \tag{65}$$

The total precession is

$$\theta_2 \approx \frac{GM}{Rc^2} \text{ radians,} \tag{66}$$

an angle equal to one-half the angle of deflection of the light beam. The sense of precession is the same as the direction of the bending.

Photon spins point parallel (or antiparallel) with the direction of the beam; accordingly (66) should numerically equal (60) in any consistent theory.

The factor of $\frac{1}{2}$ can lead to interesting speculation. Namely, if we assume that the S-gyric ratio of an orbiting particle, by quantum mechanical analogy, is different from the S-gyric ratio of a spin particle, we can construct an

$$\psi_{\text{spin}} = 2\psi_{\text{orbit}} = \frac{2J}{I\omega} = \frac{G}{c^2}. \tag{67}$$

This value gives the correct result in (66) and would multiply by a factor of 2 Eq. 49, as well as modify Eq. 53.

The introduction of ψ_{spin} however, apart from the argument that it gives the correct answer, is not justified and needs further study. It is interesting to note, however, that the appearance in the macroscopic domain of an effect which is considered quantum mechanical in origin is noted in a recent letter by Motz (11). In that correspondence the fine structure constant of atomic physics is extended to the angular momentum and charge of the sun.

7. *The Gravitational Red Shift*

It has been stated that the gravitational red shift is the least sensitive test for general relativity. In the words of Whitrow ". . . this effect is essentially a special relativistic effect arising when the ideas of that theory are applied to the study of gravitational fields." This conclusion is also reached by Schiff (12) and by Schild (13) through the use of the special theory and the equivalence principle.

Since the theory of inertial fields admits the tenets of special relativity and includes, in fact it leads to the principle of equivalence, the existing treatises concerning the gravitational red shift in terms of special relativity and the equivalence principle satisfy the spirit of the present paper.

8. *Spin-Gravitational Recoil*

Consider the second inertial field equation

$$\nabla \times \boldsymbol{S} = 4\pi \mathbf{P} + \frac{\partial \mathbf{u}}{\partial t} = 4\pi(\mathbf{P} + \boldsymbol{P}). \tag{18}$$

The presence of displacement momentum density $\boldsymbol{P}$ indicates absorption or emission of momentum; the quantity $\boldsymbol{P}$ can be thought of as establishing momentum density between emitter and absorber. A change in the rate of such emission or absorption should lead to an experimentally detectable spin-gravitational recoil.

If one is not aware of the existence of a displacement momentum density, the terms of Eq. 18 will contain only the known observables, that is

$$\nabla \times \boldsymbol{S} = 4\pi \mathbf{P}. \tag{68}$$

This statement is dimensionally correct though wrong from the point of view of conservation of momentum. Replacing $\boldsymbol{S}$ by $\frac{1}{\beta}\mathbf{S}$ and integrating over the volume of the body, we get

$$\frac{1}{4\pi}\iiint \frac{1}{\beta}\nabla \times \mathbf{S}dv = \iiint \mathbf{P}dv = \mathbf{p}. \tag{69}$$

This is essentially the relation obtained by Costa de Beauregard (4) from the complete theory of relativity, except that in his equations spin density is described by angular momentum density $\mathbf{L}$ rather than by S-flux density $\mathbf{S}$.

The complete statement should read

$$\mathbf{p} = \frac{1}{4\pi}\iiint \frac{1}{\beta}\nabla \times \mathbf{S}dv = \iiint \mathbf{P}dv + \iiint \boldsymbol{P}dv, \tag{70}$$

that is, it should include the volume integral of displacement momentum density and thus maintain the principle of conservation of momentum.

Equation 70 predicts that if a body whose spin flux density has zero curl develops a spin flux density of non-zero curl, an experimentally detectable inertial recoil should be generated.

9. Inertial Radiation

In the present paper a complete and meaningful identity of the electromagnetic and inertial field equations was assumed. The similarity was extended to phenomena that appear to be common to the two systems of fields, such as the existence of Lorentz forces. The complete symmetry of formalism can be further extended to the problem of inertial radiation.

In electrodynamics the radiation field of a moving system can be conveniently handled to sufficient accuracy by considering independently its electric dipole, electric quadrupole and magnetic dipole components.

We note, however, that for all systems in which the charge-to-mass ratio of all the moving charges is the same, the electric and magnetic dipole components of the field vanish (**14**, Secs. 9–2 and 9–5). For instance, the total intensity of electromagnetic radiation for elliptic motion of two attracting charges (**14**, Sec. 9–4) is

$$I = \frac{2e_1^2e_2^2}{3c^2}\left(\frac{e_1}{m_1} - \frac{e_2}{m_2}\right)^2 \frac{1}{r^4} \qquad [I] \equiv ML^2T^{-3} \tag{71}$$

where e_1 and e_2 are the charges, m_1 and m_2 the masses of the particles and r is their separation. It is clear that for constant

$$\frac{e_1}{m_1} = \frac{e_2}{m_2} = \frac{e}{m} \tag{72}$$

Eq. 71 equals zero.

Dipole radiation from a wire-carrying current is possible for the simple reason that the radiating system, as a whole, is made up of particles with different charge-to-mass ratios.

In electromagnetic theory the charge-to-mass ratio is the ratio of the measure of that aspect of the particle that responds to electric fields (or changing magnetic fields) to the measure of the inertial behavior of the same particle.

The identical quotient in the theory of inertial fields is the ratio of the measure of that aspect of the particle that responds to gravitational fields (or changing S-fields) to the measure of the inertial behavior of the same particle; in other words, the ratio of gravitational to "inertial" mass. By the principle of equivalence (Section III-15) this ratio is constant for all aggregates of positive masses. It follows that the lowest order component of inertial radiation is of quadrupole nature. While the Maxwell equations of inertial fields would permit the writing of wave equations for dipole radiation, the more subtle considerations of the present section prohibit such solutions for naturally occurring systems.

The calculations of the energy radiated by moving bodies in the form of inertial waves are completely analogous to those carried out for quadrupole radiation of electromagnetic waves. The role of this radiation in the energy balance of nature has been investigated and is believed to be negligible (**15**). The system of Sun and Jupiter, for example, radiates 450 watts, corresponding to a loss of mass of 5×10^{-12} g/sec.

General relativity imposes a further restriction on radiated inertial ("gravitational") fields, namely that these fields must be weak for the simple quadrupole solutions to hold. Relativity requires weak fields so that the "primary" radiation field does not interact with the gravitational field of the mass equivalent of the radiated (inertial) energy.

This restriction is removed in the theory of inertial fields by the assumption of Section III-16.

The realization that inertial radiation is of quadrupole character is in complete agreement with relativity; thus, it is by no means a novel result. The simplicity of argument permitted by the theory of inertial fields, however, and the clear relation of the quadrupole nature of the field to the principle of equivalence as revealed in this section is rather interesting.

10. Quantization of Mass

Dirac (16) has shown that "if one supposes that a particle with a single magnetic pole can exist and that it interacts with charged particles, the laws of quantum mechanics lead to the requirement that the electric charges shall be quantized. . . ."

The complete symmetry of electromagnetic and inertial fields suggests that the consequences of the existence or non-existence of *S*-poles be explored by the method employed by Dirac with special regard to predictions concerning the quantization or nonquantization of mass.

11. A Cosmological Equation

The forces which are thought of as forming the bond between distant parts of the Universe are believed to be of gravitational origin. In terms of the theory of inertial fields, a more complete statement should include forces of gravitational *and* *S*-nature, emphasizing that inertial fields form the field structure of the Universe. Because of this ubiquity of inertial fields, it is suggested that the smoothed-out model of inertial fields be identified with the cosmological substratum.

Let the expression for gravitational flux density (Eq. 3) be substituted in field equation (I). Noting (6) we get

$$\nabla \cdot \mathbf{T} = 4\pi G\rho. \qquad [\nabla \cdot \mathbf{T}] \equiv \frac{1}{T^2} \tag{73}$$

We see that the reciprocal of the divergence of gravitational field intensity has the dimension of (time)^2. It is reasonable to expect that a quantity that has time alone as its dimension can be observed as some characteristic time of a process, in this case some characteristic time of the smoothed-out model of inertial fields, that is, of the substratum. Let this time be designated by τ and related to the divergence of $\mathbf{T}$ through

$$\nabla \cdot \mathbf{T} = 4\pi\Lambda \frac{1}{\tau^2} \tag{74}$$

where Λ can be called a cosmological constant. Combining Eqs. 73 and 74, we have

$$G\rho\tau^2 = \Lambda. \tag{75}$$

This equation is well known as one of the "numerical coincidences" of cosmology, where ρ is the average density of the universe, τ is the "age of the Universe" and the quantity Λ, as determined from present measurements, has a value close to unity. If the value of Λ can be determined from other considerations, Eq. 75 can become an identity instead of being a numerical coincidence.

12. Newton's Second Law

A rather well-known and very useful static model of the Universe is a sphere of radius R and average density ρ. The radius corresponds to the limit of the observable Universe and is related to the "age of the Universe" τ through

$$R = c\tau. \tag{76}$$

We shall employ this model for the derivation of some inertial relations.

In Fig. 6 a point mass is shown accelerating upward with respect to

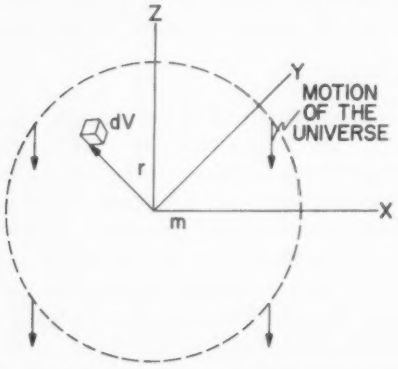

FIG. 6. Acceleration of the spherical, static model of the Universe with respect to the observer at its center.

an observer stationary in the coordinate system of the "fixed stars." From the point of view of the observer the Universe represented by the spherical model, accelerates downward. A small volume element dV of density ρ at a distance r from the observer now can be thought of as producing a gravitational field intensity at the position of the observer. This field intensity can be calculated if one remembers the complete identity of inertial and electromagnetic formalism. This identity permits the writing of an expression for the radiation field of an accelerated mass (17), including a dc-term of static gravitational field intensity. Using the spherical model of the Universe, one can integrate the equation

$$\mathbf{T} = \int \frac{G\rho}{r^3}\, dV\mathbf{r} + \int \frac{G}{c^2}\,\rho\,\frac{dV}{r^3}\,[\mathbf{r} \times (\mathbf{r} \times \mathbf{a})] \tag{77}$$

over all of space. The first term vanishes and the total gravitational field intensity becomes

$$\mathbf{T} = -\tfrac{4}{3}\pi G\rho \frac{R^2}{c^2}\mathbf{a}. \tag{78}$$

The presence of a gravitational field at the observer's position can be detected by the force it exerts on a test mass m. This force, from Eq. 78 and the cosmological equation (75), is

$$\mathbf{F} = m\mathbf{T} = -\tfrac{1}{3}\pi\Lambda m\mathbf{a}. \tag{79}$$

The direction of the force is opposite to the direction of acceleration. From its magnitude and from its direction, $-m\mathbf{a}$ is recognized as the Newtonian inertial force. To make (79) agree with observation, we must choose

$$\Lambda \equiv \frac{3}{4\pi}. \tag{80}$$

The arguments in this section are identical to those given by Kaempffer, except that the existence of inertial radiation is recognized as an organic part of the theory of this paper, rather than as an *ad hoc* assumption.[10]

13. Centrifugal and Coriolis Acceleration

In Section III-2 we discussed the effects of the Sun's rotation on an orbiting planet. We note that an observer placed on the orbit of the planet should be able to detect the Sun's S-field by observing, for instance, a slow inertial Larmor precession, but without being able to identify the "cause" of his S-field. If the observer has a velocity along the orbit of the planet, he will still experience an S-field of undiminished magnitude (Eq. 28) and also a small gravitational field (Eq. 30). This small incremental gravitational field is the agent responsible for the "additional advance of the perihelion" recognized by the general theory of relativity and by the theory of inertial fields (Section III-2). In review, the small gravitational field, pointing along the radius vector and opposite to the Newtonian acceleration, appears

[10] In the present and the following Sections where the spherical static model of the Universe is used, it is good to keep in mind the general remark of Dicke (R. H. DICKE, *Am. J. Phys.*, Vol. 28, p. 344 (1960)): "This description is queer on causal grounds, for distant matter must be accelerated before the inertial reaction is needed if gravitational waves are to propagate with the velocity of light. However, it must be emphasized that this description is not meant to be causal. It is only one of the many possible descriptions of the relative motion of the body and the Universe. We do not say that inertial forces are *caused* by the acceleration of distant matter, but that a permissible description of inertial reactions is one which considers these forces to be gravitational in origin."

(*a*) because the observer is in an *S*-field (whose source he does not have to identify), but whose presence he can experimentally detect, and
(*b*) because the observer has a velocity with respect to the non-rotating framework of the Universe.

In the present section we propose to show that centrifugal and Coriolis accelerations can be completely accounted for by realizing that because of his motion

(*a*) the observer is in an *S*-field (whose source he does not have to identify), but whose presence he can experimentally detect, and
(*b*) because the observer has a velocity with respect to the non-rotating framework of the Universe.

It can be shown that a solid spherical body rotating at a rate of ω radians per second with respect to the framework of the "fixed stars" generates an *S*-field intensity of

$$S_0 = -S_z = -\tfrac{4}{3}\pi\rho\omega R^2 \tag{81}$$

at its center. If such a spherical body is now identified with the Universe, it is meaningless to consider again another framework external to it. This uniqueness is a difficulty peculiar to cosmology and forces one, in absence of an ability "to distinguish on purely observational grounds, between its general and peculiar features"[11] to choose axiomatic features which are consistent with the theory proposed—and which possibly lead to correct answers to local experiments.

We recall that in the case of the external solution for a rotating sphere (Eq. 42) the *S*-field appears as an entity, a "flux," fixed in the framework of the Universe and attributed to rotation of the body with respect to the Universe. The same can be said about the internal solution (81): the *S*-field intensity in the sphere appears as an entity, a "flux" fixed in the framework of the Universe and attributed to the rotation of the sphere with respect to the Universe. Now, if the sphere is extended in size to become identical with the Universe, the requirement that the sphere rotate with respect to the Universe is meaningless. We propose that for this cosmological problem the *S*-field generated by the relative rotation of the observer and the Universe still be that given by (81) and that this *S*-field still be considered a "flux" stationary in the coordinate system of the fixed stars.

An observer positioned in the equatorial plane of the spherical Universe at a distance r from the center and having a tangential velocity v_x, should be able to detect by an inertial Larmor experiment an

[11] For a discussion of this problem, see (18, Section 1.3).

S-field of a magnitude which is only slightly different from that given by (81). He does not have to identify the source of the field; in fact he may attribute the *S*-field to the rotation of a local mass. In this sense his inability to differentiate between an *S*-field due to a local mass and an *S*-field due to his rotation with respect to the Universe is an expression of the *equivalence principle for rotary motion.*

The observer has a velocity with respect to the non-rotating coordinate system of the Universe (in which the *S*-field is stationary), thus he should be able to detect not only an *S*-field but also the presence of a gravitational field

$$T_y' = -\frac{G}{c^2} v_x \mathcal{S}_0 = \frac{G}{c^2} r\omega \mathcal{S}_0 = G\rho \frac{R^2}{c^2} \frac{4}{3} \pi r\omega^2. \tag{82}$$

Remembering the cosmological equation (75) we get

$$T_y' = \Lambda \tfrac{4}{3} \pi r\omega^2. \tag{83}$$

The quantity $r\omega^2$ both as to its magnitude and its direction is recognized as the centrifugal acceleration. To make (83) agree with observation, we must choose

$$\Lambda \equiv \frac{3}{4\pi}. \tag{84}$$

An interesting question can now be asked.[12] Can one find an expression for the *S*-field intensity generated by a rotating local body, in terms of the *S*-field intensity of the Universe rotating around the body?

We have

$$\mathcal{S}_z = \frac{I\omega}{2r^3} = \frac{k^2 m\omega^2}{2r^3\omega} = \frac{T_y' km}{2r^3\omega} \tag{42}$$

where k is the radius of gyration, T_y' is the centrifugal acceleration. Using (83), we get

$$\mathcal{S}_z = \frac{\beta \mathcal{S}_0 k\omega km}{2r^3\omega} = \frac{\beta}{2} I \frac{\mathcal{S}_0}{r^3}. \tag{85}$$

This equation states that the *S*-field intensity generated by the relative rotation of a local mass with respect to the Universe can either be calculated by (42) from the moment of inertia of the body and its relative angular velocity or by (85) using the moment of inertia of the body and the *S*-field intensity of the rotating Universe.

Let us now assume that the particle has a radial velocity translating in the equatorial plane toward the center of rotation. This time we

[12] The author is indebted to I. A. Greenwood for suggesting this approach.

must use the more general transformation equation (33) and apply it to the problem at hand. We have

$$T_x' = -\frac{G}{c^2}\,\mathfrak{s}_x v_y. \tag{86}$$

The gravitational field attributable to the translation of the particle in the S-field of the Universe points along the X axis

$$T_x' = -\frac{G}{c^2}\,(-\tfrac{4}{3}\pi\rho\omega R^2)v_y = \Lambda\tfrac{4}{3}\pi v_y\omega. \tag{87}$$

There is also an acceleration along the X axis, caused by motion along the radius vector. That is, we have

$$v_x = \omega r. \tag{88}$$

Taking the derivatives of both sides with respect to time, the elementary relation is

$$\frac{dv_x}{dt} = a_x = \omega\frac{dr}{dt} = v_y\omega. \tag{89}$$

The quantity $2v_y\omega$ can be recognized both as to its magnitude and to its direction as the Coriolis acceleration. Since one half of this quantity (Eq. 89) is of linear inertial origin, we have to account only for the other half as embodied in (87). To make (87) agree with observation, we much choose

$$\Lambda \equiv \frac{3}{4\pi}. \tag{90}$$

14. Mach's Principle

Mach's Principle, as it is interpreted today, refers to the suspected causal relation between inertial manifestations in the local frame and the presence of matter over all of the Universe. It is clear from Sections III-12 and III-13 that a permissible description of the inertial properties of matter in rotation and in translational motion can be given through gravitational and S interaction between the test mass and all other masses of the Universe, at least for the simple spherical model of the Universe, through the approach afforded by the theory of inertial fields. The numerical coincidence (75) becomes an identity

$$G\rho\tau^2 = \frac{3}{4\pi} = 0.23873. \tag{91}$$

A lively discussion concerning the pros and cons of Mach's Principle is going on in the literature, the pros notably led by D. W. Sciama.

Sciama (2) showed that the value of A must be of the order of unity, in agreement with Bondi's results (18). Kaempffer (17) showed that the value of this constant is $3/4\pi$ for linear acceleration and $3/2\pi$ for rotational acceleration. Einstein obtained (19) for a particular Friedman universe the value of $3/8\pi$. From best available astronomical values Zimmerman (20) calculated 0.238.

Because of the construction of integral (77), the inertia of local mass arises almost entirely through interaction with very distant masses of the Universe. If one assumes that these distant masses are electrically neutral, the entity of inertia should be absent in electrodynamics; that is, charge should have no primary inertial manifestation. This is a conclusion that can also be reached through general relativistic arguments (21) and is consistent with experimental evidence.

A further interesting thought is that a study of integrals (81) and (77) for observers located at arbitrary positions with respect to the center of the spherical model of the Universe should be instrumental in answering the question of Bondi and Kilmister (22) concerning the precise determination of the extent of a "local" frame.

As a tribute to Ernst Mach, Austrian physicist and philosopher (1833–1916) who predicted the existence of an intimate bond between inertia and the distribution of mass in the Universe we propose to refer to the number $3/4\pi$ as Mach's Cosmological Constant.

15. The Equivalence Principle

a. Nomenclature

The subject matter of this paper is a theory of *inertial fields*. This generic expression as defined in Section II-6 signifies the combined structure of *gravitational and S-fields*.

The behavior of matter in gravitational fields is conveniently described through the attribute of *mass* (sometimes called passive gravitational mass); the behavior of matter in *S*-field is conveniently described by using the concept of *S*-mass.

Inertial manifestations comprise the physical phenomena related to mass and *S*-mass in inertial fields.

The Newtonian concept of "inertial" mass is thought of as an attribute of ponderable matter helpful in describing its resistance to acceleration. Whenever this Newtonian concept is called for, "inertial" appears in quotation marks.

b. The Equivalence Principle

The arguments of Sections III-12 and III-13 embodying in essence Mach's Principle, suggest that "inertia" is an interaction of mass with the inertial field of the Universe. Accordingly, the gravitational field

intensity calculated by an observer in an arbitrary reference frame for an arbitrary position in that frame completely determines the motion of a test particle with respect to that observer. The magnitude and direction of vector **T** then includes the effects of local matter as well as the effects of distant matter, if the observer happens to be accelerating or rotating. In the particle's own frame the gravitational field intensity vanishes.

It is clear that in this approach "inertial" mass as an entity different from (gravitational) mass does not exist, and

$$\frac{m_{\text{inertial}}}{m_{\text{gravitational}}} \equiv \frac{m_{\text{gravitational}}}{m_{\text{gravitational}}} \equiv 1. \tag{92}$$

The physical essence of (92) should be called the "identity principle," emphasizing that it involves more than a numerical equivalence or the realization that m_{inertial} and $m_{\text{gravitational}}$ are experimentally inseparable.

c. Positive and Negative Masses in Gravitational Fields

The complete symmetry of inertial and electromagnetic formalism of this paper suggests that a search for "negative mass" may be meaningful.

The concept of negative and positive masses and their relation to the equivalence principle has been studied by several workers. In this paper we are adapting the approach of Costa de Beauregard (**23**). His approach is based on wave mechanical arguments but his conclusions are of a classical nature and can be well accommodated within the structure of the theory of inertial fields. His arguments and conclusions are summarized below.

The relative acceleration of two masses m_1 and m_2, as measured by an inertial observer and neglecting any relativistic corrections is

$$\mathbf{a} = -G\frac{m_1 + m_2}{r^3}\mathbf{r}. \tag{93}$$

The negative sign, consistent with our own usage, represents a decrease of distance between the masses, generally referred to as "attraction"; the positive sign represents an increase of distance, or "repulsion." It follows that

(*a*) Two positive masses attract. (93)

(*b*) Two negative masses repel, for

$$\mathbf{a} = -G\frac{-(m_1 + m_2)}{r^3}\mathbf{r} = G\frac{m_1 + m_2}{r^3}\mathbf{r}. \tag{94}$$

(*c*) A negative and a positive mass attract or repel, depending on the relative magnitudes of the masses. That is;

for $|-m_1| > |+m_2|$

$$\mathbf{a} = -G\frac{-m_1+m_2}{r^3}\mathbf{r} = G\frac{\Delta m}{r^3}\mathbf{r} \tag{95}$$

and for $|-m_1| > |+m_2|$

$$\mathbf{a} = -G\frac{-m_1+m_2}{r^3}\mathbf{r} = -G\frac{\Delta m}{r^3}\mathbf{r}. \tag{96}$$

(*d*) A positive and negative mass of equal magnitude[13] are gravitationally neutral, for

$$\mathbf{a} = -G\frac{-m+m}{r^3}\mathbf{r} = 0. \tag{97}$$

(*e*) In the gravitational field of a large body both negative and positive masses fall in the same direction and accelerate at the same rate for, if

$$m_1 \gg m_2 \qquad \therefore \qquad \mathbf{a} \approx -G\frac{m_1}{r^3}\mathbf{r}. \tag{98}$$

d. Charged Positive and Negative Masses in Gravitational and Electric Fields

The study of the behavior of mass in the presence of non-gravitational forces (again, neglecting nuclear forces) amounts to the study of charged particles in gravitational and electric fields.[14] The reason is three-fold. First, the only non-inertial field entities recognized on the macroscopic scale are electromagnetic fields. Second, there being no first order interaction between mass and electric and magnetic fields, in the present theory, one must think of a charged particle. Third, the ubiquity of the inertial field of the Universe precludes the choice of any region of space which is sufficiently distant from ponderable mass so that gravitational effects are negligible (**24**).

Consider now a coordinate system where the magnitude of the **T** vector is known, for example, pointing along the positive Z direction. An uncharged positive or negative mass particle will accelerate in the negative Z direction, let us say downward. A positive mass particle

[13] A consistent analysis of this configuration shows that while the relative acceleration is zero, the gravitational interaction of the two particles results in the negative mass "chasing" the positive mass (compare with H. BONDI, *Rev. Mod. Phys.*, Vol. 29, p. 423 (1957)).

[14] The force exerted by a solid on another solid, for example, the elastic force of a spring on a test mass, can be properly thought of as an interaction of this type; namely, the interaction of charges and electromagnetic fields of particles in the adjacent solid surfaces.

charged with what we recognize as a "negative" charge will be kept in equilibrium if a positive charge is applied to a condenser plate above the particle; that is, if the particle is in an electric field with the **E** vector pointing parallel with the **T** vector. We have the electric and gravitational forces equal and opposite, that is

$$\mathbf{F}_{\text{grav}} + \mathbf{F}_{\text{electric}} = m\mathbf{T} - q\mathbf{E} = 0. \tag{99}$$

In fact, (99) embodies the definition of electric field intensity in terms of quantities which can be measured by other experiments, namely the force of gravity and the quantity of electric charge.

The replacement of m with $-m$ in (99) would indicate that to reach equilibrium we would have to change the direction of the electric field or the charge on the particle. In other words, (99) appears to offer a method of separating positive and negative masses. This result is at variance with the presently prevalent view, such as that of Schiff (**25**), contending that the inertial and gravitational mass of all matter is positive.

While our arguments appear to be straightforward, the particular conclusion concerning the separability of positive and negative mass, if negative mass indeed exists, needs further study.

16. Electromagnetic and Inertial Fields

The complete identity of electromagnetic and inertial field equations suggests a relation of *symmetry* between the two field structures. By symmetry we mean a correspondence between electromagnetic and inertial quantities. For example, mass corresponds to charge, and an S-dipole corresponds to a magnetic dipole.

One can also discover a relation of *reciprocity* between the two fields. For instance,

$$E_{\text{electromagnetic radiation}} = c^2 \text{ (mass)} \tag{100}$$

where the left-hand side belongs to one set of fields, while the right-hand variable belongs to the other set. The constant of proportionality is the square of the speed of light.

The symmetry of the two fields appears to be complete even though some of the consequences, for example, the non-existence of inertial dipole radiation, are not identical. Reciprocity, however, as expressed by (100) alone is one-sided. We propose another equation of reciprocity, namely

$$E_{\text{inertial radiation}} = c^2 \text{ (charge)} \tag{101}$$

as a complement to (100). We note that neither of these relations affects the identity of the quantities described. What they state, for

instance, is that the annihilation of mass results in electromagnetic energy, while the annihilation of charge results in inertial energy. It also suggests that the energy of electromagnetic radiation has an equivalent mass, while the energy of inertial radiation has an equivalent charge. It follows that the energy of inertial radiation does not gravitate. It further follows, provided that the relation of reciprocity embodied in (101) correctly describes nature, that the writing of linear wave equations would be permissible, for inertial field-energy density would not act as a source of radiation. It is not suggested, however, to extend the reciprocity argument to include kinetic and potential energies; that is, $E_{\text{kin}} \neq c^2$ (charge) and $E_{\text{pot}} \neq c^2$ (charge).

17. Miscellaneous Observations

a. The "Reality" of S-fields

If the effects attributable to S-fields apart from the Coriolis and centrifugal accelerations were sufficiently large and easily accessible by experiment, one can conjecture that these effects (for example, inertial Larmor precession, inertial cyclotron motion) would have been analyzed in terms of a linear theory perhaps similar to the one proposed in this paper, long before the more sophisticated and more complete theories of general relativity were developed. For such a case, it seems, the general relativistic corrections would be understood to mean the corrections necessary for the adjustment of linear vector theory predictions, such as the ones listed in this paper.

It is suggested that the present theory be regarded as a simple approach for the calculation of minute effects, as a tool to be used in searching for other effects that are not easily predictable from the more complete theory, and as a possible approach to Mach's program.

It is also suggested that to the extent that predictions based on the S-field postulate agree with observation, S-fields assume as much of a "reality" as electric, magnetic or gravitational fields.

b. Electromagnetic and Inertial Fields

The complete symmetry and reciprocity of electromagnetic and inertial field equations suggests that the relation of the two fields, when they are simultaneously present in a region of space-time, be investigated.

A single set of Maxwell's equations, together with the constitutive equations for a "unified" field that divides self-consistently into electromagnetic and inertial components might form a simple first step in the creation of a combined vector formalism for electromagnetic and inertial fields.

c. Inertial Spectroscopy

Inertial Lorentz forces and inertial torques can also be looked for in atomic physics. Their study might lead to a discipline of "inertial spectroscopy," that is, the study of atomic and nuclear energy levels with inertial degeneracies removed.

The same type of "spectroscopy" can be extended to astronomical problems. The view that inertial Larmor precession of the planetary axis is a Zeeman effect in S-field provides a suitable example.

d. Exchange Energy

Inertial forces and torques can also enter the competition of inter- and intra-atomic forces. The question of whether or not they contribute significantly to the interatomic alignment of spins and relate to Dirac's concept of exchange energy is an interesting subject for investigation.

e. Other Goals

Beyond the problems already mentioned or implied, there are many others that clamor for recognition. For instance:

What are the predictions of a tensor theory of inertial fields?

How does our acquaintance with S-fields contribute to the understanding of the red shift?

What is the significance of S-fields in magnetohydrodynamics?

How do our equations behave under the assumption of secular variation in the value of "c" or "G"?

To what extent does the present theory contribute to our understanding of elementary particles?

IV. CONCLUSIONS

A self-consistent linear vector theory was presented based on the assumption of the existence of a force-field associated with rotating mass, and some predictions of the theory were discussed. It was found that several effects generally considered of general relativistic origin can be partially accounted for through this formalism. The mere prediction of general relativistic effects, partially or *in toto* are by no means unique in the present approach. Whitrow wrote recently that ". . . Although more cogent in aesthetic and general intellectual appeal than rival theories, general relativity is not unique in the result it predicts for the motion of the perihelion, deflection of light rays and gravitational red shift. The same results are obtained by some Lorentz invariant theories of gravitation."

What appears to be a unique and interesting finding of the paper is that if the consequences of our assumptions are pursued in detail we

can predict a broad array of physical phenomena. It is suggested that the present theory be regarded as a simple approach for the calculation of minute effects, as a tool to be used in the search for other effects that are not easily predictable from the more complete theory and as a possible approach to Mach's program.

Acknowledgments

The author wishes to thank I. A. Greenwood, Jr. for the many discussions of this subject and for his valuable and detailed criticism, and D. S. Bayley for his thorough review of the manuscript; W. H. Heath for his support and assistance in editing; F. B. Berger, J. P. Campbell, C. DuP. Donaldson (ARAP), G. R. Gamertsfelder, E. B. Hales, G. Sandri (ARAP) and J. H. Simpson for helpful discussions.

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APPENDIX

QUANTITIES USED IN THE STUDY OF INERTIAL FIELDS

Name	Symbol	Dimension	Equation	Magnitude in cgs Units
Gravitational field intensity	$\mathbf{T}$	LT^{-2}	1	
Gravitational flux	$4\pi M$	M	2	
Gravitational flux density	$\mathfrak{u}$	ML^{-2}	2	
Matter permittivity	α	$ML^{-3}T^{2}$	3	1.499×10^{7}
Universal constant of gravitation	G	$M^{-1}L^{3}T^{-2}$	6	6.670×10^{-8}
Matter density	ρ	ML^{-3}	7	
Matter current	$\mathfrak{M}$	MT^{-1}	8	
Matter permeability	β	$M^{-1}L$	13	7.413×10^{-29}
Spinetic dipole moment	$\mathbf{J}$	$L^{3}T^{-1}$	9	
Spinetic mass	m^{*}	$L^{2}T^{-1}$	10	
Spinetic poles	A, B			
Spinetic field intensity	$\boldsymbol{S}, \mathbb{S}$	$ML^{-1}T^{-1}$	11	
Spinetic flux density	$\mathbf{S}, S$	T^{-1}	12	
Spinetic field constant	K	ML^{-1}	15	1.344×10^{28}
Linear momentum density	$\mathbf{P}$	$ML^{-2}T^{-1}$		
Displacement momentum density	$\boldsymbol{P}$	$ML^{-2}T^{-1}$	17	
Intrinsic impedance of space for inertial waves	η	$M^{-1}L^{2}T^{-1}$	32	2.223×10^{-18}
Linear momentum	$\mathbf{p}$	MLT^{-1}	35	
Spineto-gyric ratio, orbital	Ψ_{orbit}	$M^{-1}L$	39	3.705×10^{-29}
Spineto-gyric ratio, spin	Ψ_{spin}	$M^{-1}L$	67	7.410×10^{-29}
Mach's cosmological constant	Λ		91	$\frac{3}{4\pi} = 0.2387$

MEDAL DAY PROCEEDINGS AT THE FRANKLIN INSTITUTE

October 18, 1961

Reception and Dinner

On Wednesday, October 18, 1961, approximately 371 Institute members and guests gathered to pay tribute to the men whose achievements had been recognized by the Committee on Science and the Arts during the past year. A reception honoring the 1961 Medalists was held at 6:15 P.M. in the lobby of Franklin Hall, and at 7.00 P.M. the guests assembled for dinner in the Hall. The Reverend Joseph Koci, Jr., Rector of St. Peter's Episcopal Church in Philadelphia, gave the invocation.

* * * *

During dinner, Wynn Laurence LePage, President of the Institute, thanked the members of the Hostess Committee for their assistance at the reception and for the floral decorations. Mr. LePage proposed the following toast to Benjamin Franklin:

(Addressing the statue) "Mr. Franklin, sir, you once wrote to your friend, Dr. Samuel Johnson, concerning the education of youth. You said, and I quote: 'I think with you that nothing is of more importance for the public weal than to form up and train youth in wisdom and virtue. Wise and good men are, in my opinion, the *strength* of the state, far more than riches or arms . . . and though the culture bestowed on *many* should be successful with only a *few*, yet the influence of those few and the service in their power may be very great.' Mr. Franklin, we are attempting to follow your wise counsel by dedicating the work of this great institution to the science edification of youth, in the hope and conviction that some of the many who come here will find wisdom and gain virtue. For providing us with that wise counsel, we salute you, sir.

"To Benjamin Franklin."

* * * *

Mr. G. Francis Tatnall, Chairman of the Committee on Science and the Arts, introduced the following former Medalists who were present at the dinner:

FORMER MEDALISTS ATTENDING MEDAL DAY, 1961

Year Awarded	Medalist
CRESSON MEDAL (Founded 1848)	
1903	Dr. G. H. Clamer
1953	Dr. William Blum
1960	Dr. William Francis Gray Swann
CERTIFICATE OF MERIT (Founded 1882)	
1921	Dr. Joseph S. Hepburn
1939	Mr. E. Burke Wilford
LONGSTRETH MEDAL (Founded 1890)	
1911	Dr. Joseph S. Hepburn
1923	Mr. Harry S. Parks
1948	Mr. Nicholas F. Arone
1958	Dr. George S. Crampton
1959	Mr. David M. Potter
POTTS MEDAL (Founded in 1906)	
1948	Dr. Clarence A. Lovell
1958	Mr. W. Nelson Goodwin, Jr.

Year Awarded	Medalist
LEVY MEDAL (Founded 1923)	
1938	Mr. Steward S. Kurtz, Jr.
1945	Dr. Rupen Eksergian
1948	Dr. William H. Cherry and Dr. Jan Rajchman
1960	Mr. Ezra S. Krendel
HENDERSON MEDAL (Founded in 1925)	
1937	Dr. Rupen Eksergian
1954	Mr. C. Levon Eksergian
1955	Mr. Carleton K. Steins
WETHERILL MEDAL (Founded 1925)	
1952	Mr. Albert J. Williams, Jr.
CLARK MEDAL (Founded 1926)	
1958	Mr. Frederic O. Hess
BROWN MEDAL (Founded 1938)	
1947	Mr. Karl P. Billner
BALLANTINE MEDAL (Founded 1946)	
1952	Dr. Walter H. Brattain
1956	Mr. Kenneth Bullington

MR. LEPAGE: "Thank you, Mr. Tatnall. Gentlemen, we are honored and very happy to have you back with us this evening. May you continue to regard this as *your* Franklin Institute—for you are all indeed a part of it.

"Ladies and Gentlemen, in your programs this evening you will find a page devoted to a description of just how the awards came about. Allow me to elaborate for a moment. Within a year of its founding, in 1824, The Franklin Institute established within itself a Committee on Inventions. It was the duty of the members of this Committee to examine the inventions and ideas brought to it by the scientists and engineers of those days, evaluate these ideas and advise the inventors as to their value to the community and to the world. Many of those inventions have turned into the comforts, conveniences, and necessities of our technological world today. In 1834, the name of this committee was changed to its present form, the Committee on Science and the Arts, but its work has remained intrinsically the same.

"The Committee on Science and the Arts, with the aid of its various sub-committees, seeks out, studies and investigates the work of scientists and engineers from all corners of the world. These are men whose

work has contributed most to the greater good of mankind in the physical sciences.

"When the work of a candidate has been fully and thoroughly investigated and passed by the Committee on Science and the Arts, his name is sent to the Board of Managers with a recommendation for award of one of the several medals of The Franklin Institute. The work of the Science and Arts Committee is long and exacting but out of that work have come the names of the very top scientists and engineers of our times. Some of them are here this evening and they are the candidates for tonight's awards.

"It is only proper and fitting that I should pay a particular tribute to the members of the Committee on Science and the Arts, and compliment them on the vast store of ability and knowledge which, collectively, they represent, and upon their energy and unselfish service to The Institute and to the scientific world.

"Gentlemen of that Committee, will you please stand so that we may all recognize and thank you? (*Aside*) I am proud to remain standing as a member myself."

STATED MEETING

MR. LEPAGE: "This day, Wednesday, October 18, 1961, marks the first stated meeting of The Franklin Institute for this season, and the first meeting since May 17, 1961. The minutes of that meeting were published in the June 1961 issue of the JOURNAL OF THE FRANKLIN INSTITUTE. If there are no corrections or additions to these minutes, I shall formally declare them approved as published.

. . .

"It has been the custom of The Franklin Institute to welcome into its membership each year the Franklin Medalist. This year, at the June meeting of the Board of Managers, Dr. Detlev W. Bronk, the Franklin Medalist for 1961, was recommended for Honorary Membership, to become effective today, October 18, 1961.

"Will the members of The Franklin Institute indicate their approval of this recommendation by saying 'Aye'?"

MEMBERS: "Aye!"

MR. LEPAGE: "Dr. Bronk, it is my pleasure, sir, to welcome you into Honorary Membership in The Franklin Institute of the State of Pennsylvania, and to hand you this membership card with all the privileges of full membership for life.

"Here are your membership card and certificate."

* * * *

Mr. LePage then read the following telegram from John F. Kennedy, President of the United States:

To All assembled for The Franklin Institute Medal Day, I wish to send greetings and warm congratulations to those being honored for their achievements in science and the mechanic arts.

Benjamin Franklin knew that progress in science and technology was greatly enhanced by the free and open exchange of knowledge and ideas. He sought to encourage the true universality of science and to tear asunder any barriers to free communication of truth. The Franklin Institute honors the wisdom of Benjamin Franklin by recognizing important contributions to science and technology from all corners of the world. Today, the Institute also pays tribute to those whose discoveries and achievements will redound to the benefit of all men everywhere. On behalf of my countrymen, I am pleased to extend this nation's appreciation and gratitude for those advances in new knowledge which yield their return in the progress of civilization.

JOHN F. KENNEDY

REMARKS BY THE PRESIDENT

"Ladies and Gentlemen, in giving thought to what I might say to you this evening, I took occasion to look back into the files and examine my remarks over the past three years at these Medal Award ceremonies.

"In 1958, my first year as President, I attempted to draw your attention to the mutuality of interest and understanding which exists among the scientists of the world. I pointed out by using the sage words of Dr. Franklin, that scientists should at all times find welcome in any and all countries throughout the world. Scientific and technological thinking and the free exchange of ideas and theories can never be nationalized and no attempt to do so should ever be made.

"The Franklin Institute, in its studied recognition of scientific accomplishment, knows no boundaries. Indeed this is characteristic of all of our activities. The fine Science Museum continues to entertain visitors from all over the world and the JOURNAL OF THE FRANKLIN INSTITUTE is mailed to subscribers in over fifty different countries whose scientific publications are in turn available in our Science Library.

"In our Bartol Research Laboratories in Swarthmore, an operation which I like to speak of as a gem among the great physics research establishments, we entertain scholars and fellows from everywhere regardless of nationality, and at The Franklin Institute Laboratories for Research and Development here in Philadelphia are workers from the world over. In like manner, our own staff scientists are to be found attending symposia or in consultation in all quarters of the globe.

"Yes, The Franklin Institute has an international facet in its make-up and in its outlook, so that it is only natural that we may expect to find an international quality in the selection of those outstanding men of science and technology whom we honor here this evening.

"In my remarks before this assembly in 1959, I made reference to

our growing mastery of outer space, to the actual striking of the moon by a satellite of the Soviet Union and, the following year, to our own satellite now orbiting the sun. Since then man himself has circumnavigated the Earth, not via the stormy seas of a bygone age nor by the still more stormy atmospheric skies, but far above in the still, cold blackness of outer space.

"As we learn to master space we also gain knowledge of the dangers lurking up there in the great 'beyond' of the universe. Indeed, an eminent scientist responsible for pinpointing one of the most serious of these hazards is to be honored for his work here this evening.

"Today we are bouncing radio signals off man-made globe-encircling satellites in a masterful step toward improvement in worldwide communications; we are more accurately forecasting the weather and otherwise gaining a vastly greater knowledge of our earth and the universe into which it fits. True it is that with all of this has come the development of lethal weapons; but so deadly are they that, let us hope, no man will dare to use them till finally we can all agree to destroy them.

"Less heralded, perhaps because they appeal less to the lay imagination, has been and is our technological progress in categories of science and invention on the Earth rather than beyond it. Here we have probed the mysteries of nuclear collisions—and indeed photographed them. We have developed new and improved metal alloys, further perfected our means of electromagnetic communications and attained a better insight into the mysteries of plant growth. We have improved the engineering efficiency and the efficacy of our building designs and some may say the beauty of them likewise!

"Yes, we have indeed made vast technological progress which, if backed by faith and understanding in the great and Golden Rule, should help us to bring peace, freedom, and prosperity to all mankind.

"And that the supply of engineering and scientific talent in the years to come shall not wane and the United States find itself lagging in an era of technical dominance, we at The Franklin Institute are doing our part, and upon the direction of the Board of Managers, taking steps specifically to expand and improve our services to the community and the country through our Program to Advance Science Education, announced earlier this year.

"This ten-year program, which has been described by Dr. James Killian, President Eisenhower's Science Advisor, as 'bold and well conceived' is receiving the enthusiastic and, I am very grateful to say, generous support of industry, foundations, our members and friends from all over. Already the expansion and rehabilitation are under way; many new science teaching exhibits are planned and some already completed in the great Museum. Greatly expanded workshop courses, seminars, and symposia are in process and The Institute is more and more becoming the 'science home' for young people throughout the

extensive Delaware Valley region and a pattern for institutions elsewhere across the nation.

"The Institute is experiencing capacity use of these services and, indeed I am proud to be able to announce that Museum attendance this year has been greater than ever before in the nearly thirty years since this great edifice was built. Our Laboratories are handling a greater volume of scientific research and development work than ever before in their history, while Bartol Research Foundation is forging its way to new heights in the study of basic science. It is because The Franklin Institute is dedicated to the education of the young (including the 'young' of our age) in the sciences and the mechanical arts, dedicated to the furtherance of knowledge through research and in the recognition of technical leadership, that we are here this evening.

"Gathered with us are a few of the more talented of our times, those men who, in their respective spheres, have been singled out to receive the special awards of which The Franklin Institute is custodian. Their work has enriched the comprehension of all of us and we are here to honor them."

PRESENTATION OF AWARDS

MR LEPAGE: "I have already indicated that the awards of The Franklin Institute are given regardless of nationality, creed or race, and are in recognition of unusually excellent work in the several fields of the physical sciences as recommended by the Committee on Science and the Arts.

"The recipient of each award is usually sponsored by the chairman of that Sub-Committee of the Committee on Science and the Arts which recommended him for the award. The Sponsors will please present their candidates for award and read their citations."

PRESENTATION OF THE ELLIOTT CRESSON MEDALS

(Founded in 1848)

This medal is awarded for discovery or original research, adding to the sum of human knowledge, irrespective of commercial value; leading and practical utilizations of discovery; and invention, methods or products embodying substantial elements of leadership in their respective classes, or unusual skill or perfection in workmanship.

To Donald A. Glaser, Professor of Physics, University of California, Berkeley, California; to Rudolf L. Mössbauer, Senior Research Fellow in Physics, California Institute of Technology, Pasadena, California; to Reinhold Rüdenberg, Gordon McKay Professor of Electrical Engineering Emeritus, Harvard University, Cambridge, Massachusetts; and to James Alfred Van Allen, Head, Department of Physics and Astronomy, State University of Iowa, Iowa City, Iowa.

MR. LEPAGE: "The Chair recognizes Dr. Harvey A. Neville, Sponsor for Dr. Donald A. Glaser."

DR. NEVILLE: "Mr. President, I present Donald A. Glaser for an award.

"Dr. Glaser designed the bubble chamber, a device for detecting and photographing the nuclear collisions and the resulting tracks of very high energy particles from cosmic rays or accelerating machines. Just as the Wilson cloud chamber uses the instability of a supercooled vapor against droplet formation, so the bubble chamber uses the instability of a superheated liquid against vapor bubble formation.

"When the pressure on a superheated liquid is suddenly reduced, the liquid is in a momentarily unstable state. Boiling cannot begin without the presence of nuclei upon which vapor bubbles can form. Ions may act as such nuclei. Hence, when an ionizing particle passes through the liquid in its unstable state, microscopic vapor bubbles form upon the ions along its track and rapidly grow to visible size.

DONALD A. GLASER

"I present Donald A. Glaser, of Berkeley, California, as a candidate for an Elliott Cresson Medal, 'In consideration of his invention of the bubble chamber, a device in which the tracks of high energy ionizing particles of the fragments of nuclear collisions can be photographed, thus providing a powerful tool for obtaining new information about elementary particles and processes that give rise to them.'"

MR. LEPAGE: "Thank you, Dr. Neville."

"Dr. Glaser, on behalf of The Franklin Institute of the State of Pennsylvania, I present to you this Elliott Cresson Medal and the Certificate and Report which accompany it.

"The Chair recognizes Mr. Charles M. Cooper, Sponsor for Dr. Rudolf L. Mössbauer."

MR. COOPER: "Mr. President, I present Rudolf L. Mössbauer for an award.

"As a result of his studies leading first to a Master's and then to a Doctor's Degree, Rudolf Mössbauer has given to science both a new understanding of nuclear resonance and a new measuring tool of unprecedented sensitivity. In the short years since its announcement in

1958, eager physicists have used this tool—The Mössbauer Effect—to make measurement not previously possible in such widely divergent fields as gravitation, structure of the nucleus, and magnetism. Sensitivities greatly exceeding one part in 10^{12}, that is one part in a million million, have been achieved; and the end is not yet in sight.

RUDOLF L. MÖSSBAUER

"I present Rudolf L. Mössbauer, of Pasadena, California, as a candidate for an Elliott Cresson Medal, 'For his discovery of the recoilless emission, and for his penetrating analysis and understanding of the phenomenon which has led to a tool of unbelievable discrimination now widely employed in many facets of physical research to make measurements believed impossible as little as ten years ago.' "

MR. LEPAGE: "Thank you, Mr. Cooper.

"Dr. Mössbauer, on behalf of The Franklin Institute of the State of Pennsylvania, I present to you an Elliott Cresson Medal and the Certificate and Report which accompany it.

"The Chair recognizes Mr. John H. Neher, Sponsor for Dr. Reinhold Rüdenberg."

REINHOLD RÜDENBERG

MR. NEHER: "Mr. President, I present, in absentia, Reinhold Rüdenberg for an award.

"The electric power industry, as we know it today, dates from the decade beginning in 1880 when the first central stations were built to furnish power for electric streetcars and the newly developed electric light. Dr. Rüdenberg was born with this new industry, and he has

made many significant contributions to it throughout his life, not only in the development of the basic theories involved and their practical application, but also as a teacher and counsellor of present-day engineers.

"During his career, first as chief engineer of the Siemens-Schuckertwerke in Germany and, subsequently, as Gordon McKay Professor of Electrical Engineering at Harvard University, he has patented over three hundred inventions and has written over a hundred technical articles and several textbooks, one of which has become a standard reference in the electrical art.

"I present, in absentia, Reinhold Rüdenberg, of Belmont, Massachusetts, as a candidate for an Elliott Cresson Medal, 'For his many contributions to the electric power industry for over fifty years as an engineer, inventor, author and teacher, and particularly for his scholarly textbook on transient performance of electric power systems by which present and future engineers may attain a better understanding of the problems of their profession.'"

MR. LEPAGE: "Thank you, Mr. Neher.

"Ladies and Gentlemen, unhappily Dr. Rüdenberg is confined to his bed, battling pneumonia. In his absence I call upon his son, Dr. Gunther Rüdenberg, to accept the Medal for his father."

"Dr. Rüdenberg, on behalf of The Franklin Institute, I present to you this Elliott Cresson Medal and the Certificate and Report which accompany it.

"The Chair recognizes Professor Raymond J. Emrich, Sponsor for Dr. James Alfred Van Allen."

JAMES ALFRED VAN ALLEN

PROFESSOR EMRICH: "Mr. President, I present James Alfred Van Allen for an award.

"Dr. Van Allen, Chairman of the Department of Physics and Astronomy at the State University of Iowa, is an international authority on the physics of the upper atmosphere, and, in particular, the phenomena of the trapped radiation bands encircling the earth.

"He has made continuous personal contributions toward the furtherance of space research since 1945. He pioneered in experiments with

rockets to probe the upper atmosphere, using captured German V-2 rockets and evolved the 'Rockoon' technique, which launched instrument-carrying rockets from the platform of high altitude balloons. These techniques were used successfully in making early important observations on radiation particles in the auroral zone.

"Dr. Van Allen was an early advocate of the concept of magnetic confinement. As a result of his leadership and direction, he and his co-workers at the State University of Iowa have been the leading group of experimenters in investigating the phenomena of trapped radiation particles by means of experiments carried in satellites and space probes. Dr. Van Allen planned the experiments and directed the programs to probe the upper atmosphere on Explorer I, the first United States satellite, and succeeding Explorers and Pioneer deep space probes. These programs, under his direction, led to the discovery of the great regions of trapped radiation around the earth now known as the 'Van Allen Radiation Belts.'

"I present James Alfred Van Allen, of Iowa City, Iowa, as a candidate for an Elliott Cresson Medal, 'In consideration of his many contributions and pioneering achievements in the field of space science; in particular, for his discovery of regions of trapped radiation in space, now termed the "Van Allen Radiation Belts." ' "

MR. LEPAGE: "Thank you, Professor Emrich."

"Dr. Van Allen, on behalf of The Franklin Institute, I present to you this Elliott Cresson Medal and the Certificate and Report which accompany it."

PRESENTATION OF THE EDWARD LONGSTRETH MEDALS

(Founded in 1890)

This Medal is awarded for inventions of high order and for particularly meritorious improvements and developments in machines and mechanical processes.

To Robert L. Alcorn, Jr., Research Engineer, Chambersburg Engineering Company, Chambersburg, Pennsylvania; Eugene C. Clarke, Formerly President; and Henry A. Weyer, Chief Engineer, all of the same Company; and to Josiah L. Merrill, Jr., Member of the Technical Staff, Bell Telephone Laboratories, Inc., Murray Hill, New Jersey.

MR. LEPAGE: "The Chair recognizes Mr. George M. Muschamp, Sponsor for Mr. Robert L. Alcorn, Jr., Mr. Eugene C. Clarke, and Mr. Henry A. Weyer."

MR. MUSCHAMP: "Mr. President, I present Robert L. Alcorn, Jr., Eugene C. Clarke, and Henry A. Weyer for awards.

"A century ago the demands of industry for the forming of large

pieces of metal called for more brawn than any man possessed and the power-driven hammer was born. The drop hammer, so called because it was raised by power and dropped by its own massive weight, required even larger anvils—and so more and more power was dissipated into the earth.

"Appropriately enough in this space age, came the concept of bringing hammer and anvil together horizontally in mid-air with the forging between them and so absorb the impact energy in doing useful work. Success, however, required precise control of the moving parts and this achieved by a necessarily complex hydraulic and electronic control system.

"Thus, combining the advantages of the old and the new, the 'Impacter' forging method was invented by our candidates.

ROBERT L. ALCORN, JR.

EUGENE C. CLARKE

HENRY A. WEYER

"I present Robert L. Alcorn, Eugene C. Clarke, and Henry A. Weyer, of Chambersburg, Pennsylvania, each as a candidate for an Edward Longstreth Medal, 'In consideration of their invention of the "Impacter" method for forging parts and controls therefor which marks a notable advance in the ancient art of forging toward modern utilization of this art by, among other things, substantially eliminating shock and vibration, facilitating high-speed operation and by making possible forging of metals at extremely high temperatures.' "

MR. LEPAGE: "Thank you, Mr. Muschamp.

"Mr. Alcorn, on behalf of The Franklin Institute, I present to you this Edward Longstreth Medal and the Certificate and Report which accompany it.

"Mr. Clarke, I present to you this Edward Longstreth Medal and the Certificate and Report which accompany it.

"Mr. Weyer, on behalf of The Franklin Institute, I present to you this Edward Longstreth Medal and the Certificate and Report which accompany it.

"The Chair recognizes Dr. S. Reid Warren, Jr., Sponsor for Mr. Josiah L. Merrill, Jr."

DR. WARREN: "Mr. President, I present Josiah L. Merrill, Jr., for an award.

"About 1946 it became quite clear that telephone communication in the United States would continue to be effective only if new technical advances could be achieved so that the telephone plant could simultaneously expand at a very large rate, improve in the quality of transmission, and operate at higher speeds with increasing automatization.

"A part of this problem called for the development of new methods to make it possible to use cable pairs operating over distances of twenty miles or less while maintaining direct-current continuity. To solve this problem, Mr. Merrill developed the negative-impedance booster which compensates for cable losses by introducing into the circuit a negative resistance derivable from batteries used in conjunction with solid-state or thermionic converters and linear circuit elements. He produced successful prototypes early in 1946; the practicability of the system was demonstrated in November 1947; and the commercial use of the device began in February 1949. Since 1950 more than one million negative-impedance boosters have been installed in telephone systems not only in the United States but in other countries as well.

JOSAIH L. MERRILL, JR.

"I present Josiah L. Merrill, Jr., of Murray Hill, New Jersey, as a candidate for an Edward Longstreth Medal, 'For his analysis of problems associated with losses and distortion in telephone transmission systems; for his synthesis of the negative-impedance booster; and particularly for his successful development of a negative-impedance booster system that has proved to be highly effective and economical.' "

MR. LEPAGE: "Thank you, Dr. Warren.

"Mr. Merrill, on behalf of The Franklin Institute of the State of Pennsylvania, I present to you this Edward Longstreth Medal and the Certificate and Report which accompany it."

PRESENTATION OF THE LOUIS E. LEVY MEDAL

(Founded in 1923)

This Medal is awarded to the author of a paper of especial merit, published in the JOURNAL OF THE FRANKLIN INSTITUTE, preference being given to one describing the author's experimental and theoretical researches in a subject of fundamental importance.

To John H. Holland, Assistant Professor of Communication Sciences, The University of Michigan, Ann Arbor, Michigan.

MR. LEPAGE: "The Chair recognizes Professor George W. Patterson, 3rd, as Sponsor for Dr. John H. Holland."

PROFESSOR PATTERSON: "Mr. President, I present John H. Holland for an award.

"His paper, 'Cycles in Logical Nets,' presents results of investigations concerning the behavior of such systems as modern computers and control devices utilizing discrete signals. We shall here call these systems logical nets.

"It has been known for some time that delay elements are essential for the functioning of logical nets that have storage or memory capabilities. It is also known that these delays must be arranged in feedback loops, or cycles, in order to be effective.

JOHN H. HOLLAND

"Holland is the first to analyze these cycles and link up their complexity with the behavior of the net. He was able to show for certain classes of nets how the spectrum of (necessarily) periodic output sequence is related to a periodic input sequence.

"The analytical methods used to establish this and other important results in the paper are likely to prove fruitful in the analysis of other complicated problems.

"I present John H. Holland, of Ann Arbor, Michigan, as a candidate for the Louis E. Levy Medal, 'In recognition of his outstanding paper, "Cycles in Logical Nets," appearing in the September 1960 issue of the JOURNAL OF THE FRANKLIN INSTITUTE.'"

MR. LEPAGE: "Thank you, Professor Patterson.

"Dr. Holland, on behalf of The Franklin Institute of the State of Pennsylvania, it gives me pleasure to present to you this Louis E. Levy Medal and the Certificate and Report which accompany it."

PRESENTATION OF THE JOHN PRICE WETHERILL MEDALS

(Founded in 1925)

This Medal is awarded for discovery or invention in the physical sciences or for new and important combinations of principles or methods already known.

To Albert E. Hitchcock, and Percy W. Zimmerman, Boyce Thompson Institute for Plant Research, Yonkers, New York.

MR. LEPAGE: "The Chair recognizes Dr. Joseph S. Hepburn, Sponsor for Dr. Albert E. Hitchcock and Dr. Percy W. Zimmerman."

DR. HEPBURN: "Mr. President, I present Albert E. Hitchcock and, posthumously, Percy W. Zimmerman."

"As early as 1933, Percy W. Zimmerman and Albert E. Hitchcock

ALBERT E. HITCHCOCK

PERCY W. ZIMMERMAN

published the results of their researches on the production of adventitious roots on plants by various gases. The study was broadened to include the action of numerous organic chemical compounds in inducing root growth, controlling bud formation, and influencing other asepcts of plant growth. The results of these researches have found application in agriculture.

"I present Albert E. Hitchock, of Yonkers, New York, and, posthumously, Percy W. Zimmerman each as a candidate for a John Price Wetherill Medal, 'In consideration of their researches on the chemical factors controlling the growth of plants, which have found application in agriculture.'"

MR. LEPAGE: "Thank you, Dr. Hepburn.

"Dr. Hitchcock, on behalf of The Franklin Institute of the State of Pennsylvania, I present to you this John Price Wetherill Medal and the Certificate and Report which accompany it.

"Mrs. Zimmerman, will you accept this Wetherill Medal and the Certificate and Report which accompany it, awarded to your husband, the late Dr. Zimmerman."

PRESENTATION OF THE FRANK P. BROWN MEDAL

(Founded in 1938)

This Medal is awarded to inventors for discoveries and inventions involving meritorious improvements in the building and allied industries.

To Charles-Edouard Le Corbusier, Architect, Paris, France.

MR. LEPAGE: "The Chair recognizes Mr. J. Roy Carroll, Jr., Sponsor for Le Corbusier."

MR. CARROLL: "Mr. President, I present, in absentia, Charles-Edouard Le Corbusier, for an award.

"Traditionally, the Frank P. Brown Medal has been awarded either for a single unique contribution to the art and science of building, or in recognition of a lifetime of the highest professional accomplishment of an architect or engineer. The recommendation of an appropriate award to this nominee could have been made properly in either category.

"Many of the very names which today are used to describe the significant parts of a modern building define forms which appeared in this man's imaginative designs almost fifty years ago. The tremendous stature of his long and fruitful professional life is fully revealed by the opinion of the majority of his colleagues all over the world who consider Le Corbusier to be the most influential architect of our time.

CHARLES-EDOUARD LE CORBUSIER

"I present, in absentia, Charles-Edouard Le Corbusier, of Paris, France, as a candidate for the Frank P. Brown Medal, 'For a lifetime of creative leadership in the teaching and the practice of Architecture as exemplified by his modular concept of human scale, free plan, pillar foundations, glass walls, sun breaks and roof terraces; his City Planning as exemplified by the Vertical City concept and for his outstanding contributions as a sculptor and painter.'"

MR. LEPAGE: "Thank you, Mr. Carroll.

"The Chair recognizes Mr. Gilles Curien, First Secretary of the French Embassy in Washington.

"On behalf of The Franklin Institute of the State of Pennsylvania, and in the absence of Le Corbusier who is unable to be with us this evening, I present to you, Mr. Curien, this Frank P. Brown Medal and the Certificate and Report which accompany it. Will you transmit it with our expression of regret?"

PRESENTATION OF THE FRANCIS J. CLAMER MEDAL

(Founded in 1943)

This Medal is awarded at least once in five years for meritorious achievement in the field of Metallurgy.

To Russell P. Heuer, Vice President, General Refractories Company, Philadelphia, Pennsylvania.

MR. LEPAGE: "The Chair recognizes Mr. Francis B. Foley, Sponsor for Dr. Russell P. Heuer."

RUSSELL P. HEUER

Mr. Foley: "Mr. President, I present Russell P. Heuer for an award.

"The rate of production of steel in basic open-hearth furnaces, which account for over 90 per cent of all the steel made, has been increased twenty fold during the past half-century and promises to increase still more in the near future. This phenomenal increase has been made possible by the use of molten pig-iron, improved furnace design and by the use of higher operating temperatures. The use of higher temperatures, attained in recent years by the use of high purity oxygen, would not have been possible had it not been for the improvements in basic refractories capable of withstanding them. Dr. Heuer has not only pioneered research in this development and been an outstanding contributor to it continuously for the past thirty years but has designed methods of open-hearth construction which have enabled the efficient use of basic refractories.

"I present Russell P. Heuer, of Bryn Mawr, Pennsylvania, as a candidate for the Francis J. Clamer Medal, 'In consideration of his pioneer work in the composition and manufacture of basic brick and in the design of open-hearth roof structures which have been major contributing factors in materially increasing the rate of steel production from open-hearth furnaces.' "

MR. LEPAGE: "Thank you, Mr. Foley.

"Dr. Heuer, on behalf of The Franklin Institute, I present to you this Francis J. Clamer Medal and the Certificate and Report which accompany it."

PRESENTATION OF THE STUART BALLANTINE MEDALS

(Founded in 1946)

This Medal is to be awarded in recognition of outstanding achievement in the fields of Communication and Reconnaissance which employ electromagnetic radiation.

To Nicolaas Bloembergen, Gordon McKay Professor of Applied Physics, Harvard University, Cambridge, Massachusetts; H. E. Derrick Scovil, Head, Solid State Maser Department, Bell Telephone Laboratories, Inc., Murray Hill, New Jersey; and to Leo Esaki, Senior Physicist, International Business Machines Research Center, Yorktown Heights, New York.

MR. LEPAGE: "The Chair recognizes Mr. William E. Bradley, Sponsor for Dr. Nicolaas Bloembergen and Dr. H. E. Derrick Scovil."

MR. BRADLEY: "Mr. President, I present Nicolaas Bloembergen and H. E. Derrick Scovil for awards.

NICOLAAS BLOEMBERGEN

H. E. DERRICK SCOVIL

"They are responsible for the invention, construction and successful demonstration of the first solid state maser, which has made possible for the first time an electronic amplifier free from spurious noise and capable of operation anywhere in a vast frequency region extending through the ultra high frequency and microwave spectrum. Their work has greatly advanced the communication and electronic arts, especially with respect to reception of very weak signals from distant objects in space. Long range radar, radio astronomy, and worldwide communication by means of satellites have been, or soon will be, greatly improved through the use of solid state maser amplifiers.

"I present Nicolaas Bloembergen, of Cambridge, Massachusetts, and H. E. Derrick Scovil, of Basking Ridge, New Jersey, each as a candidate for a Stuart Ballantine Medal, 'For the invention of the three-level solid state maser and its subsequent development for practical use.' "

MR. LEPAGE: "Thank you, Mr. Bradley.

"Dr. Bloembergen, it gives me great pleasure to present to you on behalf of The Franklin Institute, this Stuart Ballantine Medal and the Certificate and Report which accompany it.

"Dr. Scovil, on behalf of The Franklin Institute, I present to you this Stuart Ballantine Medal and the Certificate and Report which accompany it.

"The Chair recognizes Mr. C. Raymond Kraus, Sponsor for Dr. Leo Esaki."

MR. KRAUS: "MR. President, I present Leo Esaki for an award.

"It is a matter of general agreement in the semi-conductor industry that the most important new invention of recent years is the Esaki Diode. This invention, first disclosed in 1957, has had a substantial impact on the industry. It involves a new principle of operation for a semi-conductor device; namely, quantum-mechanical tunneling. This principle frees us from the limitations of transit time; and, operation in a new frequency range is made possible. Also, these diodes can perform complex functions although they are inherently simple. Furthermore, research in tunneling physics, stimulated by this device, has led to a new understanding in semi-conductor physics.

LEO ESAKI

"Esaki's contribution is an example of outstanding individual accomplishment in an area of research that was not fashionable to examine at that time. During the course of a systematic investigation of junctions in degenerate semi-conductors—a field of investigation avoided by many because of its difficulty—Esaki observed and recognized the importance of the negative resistance effect now named after him. He pursued this opportunity in a comprehensive series of experiments involving an unusual blend of theory and experiment.

"I present Leo Esaki, of Briarcliff Manor, New York, as a candidate for the Stuart Ballantine Medal, 'For his discovery and utilization of quantum-mechanical tunneling in semi-conductors and for having pioneered an important new area of electronic investigation.' "

MR. LEPAGE: "Thank you, Mr. Kraus.

"Dr. Esaki, on behalf of The Franklin Institute, I present to you this Stuart Ballantine Medal and the Certificate and Report which accompany it."

PRESENTATION OF THE FRANKLIN MEDAL

(Founded in 1914)

This Medal is awarded annually to those workers in physical science or technology, without regard to country, whose efforts, in the

opinion of the Institute, acting through its Committee on Science and the Arts, have done most to advance a knowledge of physical science or its applications.

To Detlev W. Bronk, President, The Rockefeller Institute, New York, New York.

MR. LEPAGE: "The Chair recognizes Mr. Joseph Gray Jackson, Sponsor for Dr. Detlev W. Bronk."

DETLEV W. BRONK

MR. JACKSON: "Mr. President, I present Detlev W. Bronk for an award.

"The science of physiology owes much to the application by Dr. Bronk of his rigid training as a physicist to the study of nerve function. A major contribution is his clarification of the action of the nerves of the carotid sinus as linear recorders of blood pressure. Dr. Bronk discovered that nerves possess a primitive memory, and by this characteristic it is possible to distinguish one nerve cell from another. An American school of tissue metabolism has been erected on the contributions made by Dr. Bronk.

"He is a perfectionist, and has demonstrated to co-workers techniques in neurophysiology which have become classic.

"His great flair for organization is exhibited by his activities as organizer of the Johnson Foundation, President of the Rockefeller Institute, and President of the National Academy of Sciences.

"I present Detlev W. Bronk, of New York, New York, as a candidate for The Franklin Medal, 'In recognition of his learned investigations of electrical and biochemical properties of nerves, for his contributions to our understanding of the central and peripheral nerves, for the perfection of his experimental techniques which set an inspiring example for co-workers, and for his scientific leadership in biophysics.' "

MR. LEPAGE: "Thank you, Mr. Jackson.

"Dr. Bronk, as President of The Franklin Institute of the State of Pennsylvania, I am honored, and find great personal pleasure in present-

ing to you this highest award of the Institute, The Franklin Medal, and the Certificate and Report which accompany it."

* * *

MR. LEPAGE: "This evening, Ladies and Gentlemen, we have met here on this dais men who have worked to develop understanding of our physical world, who have shone the light of intelligence into the dark corners of ignorance, men who have brought beauty to our buildings and health to our crops; we have seen men who have looked beyond the Earth and cautioned us of some of the dangers which lie there. Gentlemen, we are honored as we in turn have tried to honor you. Now, I call upon our distinguished Franklin Medalist for 1961, Dr. Detlev W. Bronk.

"Dr. Bronk."

ADDRESS BY DETLEV W. BRONK

(See page 513 of this JOURNAL for the text of Dr. Bronk's address.)

MR. LEPAGE: "Thank you, Dr. Bronk.

"And so, Ladies and Gentlemen, we again turn over a leaf of the calendar. We have met well on this day of Medal Awards at The Franklin Institute. The hands of the clock are still turning.

"Ladies and Gentlemen, we wish you good night."

THE HUMANE QUALITIES OF SCIENCE*

BY

DETLEV W. BRONK[1]

President LePage and fellow admirers of Benjamin Franklin: It is difficult for me to speak of my great gratitude to you who have welcomed me into the fellowship of The Franklin Institute which I have known, admired and enjoyed so very many years.

Knowing last night that this evening I should be standing in the presence of your patron, I took down the first volume of the *Memoirs* of the American Academy of Arts and Sciences to see what his former colleagues of Boston had to say of Mr. Franklin who had left Boston to come to Philadelphia and here create the American Philosophical Society.

I find that in the opening pages of the *Memoirs* there is indeed reference to the fact that there is such a Society founded in Philadelphia. Little more is said. But I found a few sentences which I thought not inappropriate for this occasion.

"Societies," it says in the opening page, "for promoting useful knowledge may be highly advantageous to the communities in which they are. Men united together may oftentimes suggest such hints to one another as may be improved to important ends. And societies instituted for promoting knowledge may also be of service by exciting a spirit of stimulation. When possessed of funds sufficient for the purpose they reward the past exertions of those who have been industrious and enterprising with honorary medals which should excite them to further efforts and experiments which may result in some useful discoveries."

I don't know why that particular reference to this particular occasion and its significance in exciting work for the future reminded me of a cartoon many of you will have seen, which depicts three cavemen in a cave. One of them is sulking in a corner. The other two are in heated discussion. One says to the other, "I grant you he discovered fire, but what I want to know is what has he done since then."

My fellow recipients of honors this evening will, I know, forgive me for this allusion; after all, if they have discovered fire, one such discovery is enough.

Your kindness reminds me of many debts I would with gratitude acknowledge, especially to Philadelphians and to Philadelphia institu-

* Delivered at the 1961 Medal Day Meeting of The Franklin Institute, October 18, 1961, in acceptance of the Franklin Medal.

[1] President, The Rockefeller Institute, New York, N. Y.

tions. I vividly recall an evening in The Franklin Institute's old building (on Seventh Street it was, I think) when I was a young student first inspired by the powers science gives to man. It was an evening when voice was first carried across the continent. We heard it transmitted through one relay station after another, and finally heard seals at the Golden Gate. It was an inspiration for a young man deciding what should be his career.

I am reminded of Eldridge Reeves Johnson, whose faith and generosity to a company of young men enabled us to create the Johnson Foundation where for more than thirty years the physical sciences have been used to explore the sciences of life.

I have a deep debt of gratitude to the University of Pennsylvania which gave me freedom to do what I chose to do for twenty years, and then with this typical generous spirit enabled me to remain part of her during my associations with sister institutions.

I keep thinking often of your patron saint who has been an inspiration to all of us who have received your medals on this evening. Last evening as I left my study in Washington, Mr. Franklin, I looked up at a record on the wall taken from the book of the Royal Society; and there, sir, it says: "Benjamin Franklin, Esquire, of Phildelphia, a gentleman who has very eminently distinguished himself by various discoveries in natural philosophy and who first suggested experiments to prove the analogy between lightning and electricity, being desirous of being elected a Fellow of the Royal Society is recommended by us in consideration of his great merit and because of his many communications is highly deserving of the honor he desires."

And, sir, I see there listed as signatures the Earl of Masefield, Lord Parker and seven others. Your were first proposed on the 29th of January, 1756. The Fellows debated your qualifications seven times and finally on the 29th of May of that same year you were elected.

The fact that the Philadelphian had thus achieved worldwide distinction meant a great deal to me as a young man, but I should go on to say that I speak of these debts of gratitude not because you are concerned with my emotions but because I would remind you and acknowledge on behalf of my colleagues of this evening that a scientist depends on others and upon institutions in unique degree.

From the universities which we hold precious we have gained so much that we would to them say that all that we have been honored for is due to them and to our colleagues of the past and those with whom we have the privilege of working in the present.

In these times of uncertainty and, often, fear I need not say that the furtherance of science is necessary to our national security, necessary to an expanding economy for a growing population, necessary I presume to our national competitive prestige, necessary to our protection against the agents of disease and death. We must survive in order that we may live.

But I would speak tonight of other values that are derived from science, values that are a heartening source of hope and courage, and give significant purpose and dignity to life.

During this past year there have been many scientific assemblies throughout the world, gatherings of scientists from many countries. In many that I have attended I have found continual reference to the dignity of life.

Science, said an eminent Philippine scientist, has awakened and found its center in man. All efforts of science must be directed toward the preservation of man's dignity.

Vidal Kahn was repeating what he had said at a previous Pacific science congress when warring nations were again united. He was thinking of the need for restoring dignity to man despite the recent efforts of man to impose his inhumanity on man.

As I asked Professor Kahn why it was that he and so many others continually spoke of human dignity as a product of scientific effort, he replied, "I suppose it is because we recognize in science the qualities of a great odyssey of the human spirit, an odyssey which we need to recognize in these times that are so materialistic."

We should certainly be callous to the hopes and fears of man if we did not have a deep concern for the wiser, more humane use of scientific knowledge.

I often think of an evening flight from Washington to New York one brilliant winter evening several years ago. Because I have been priviliged to fly so very many years I have never lost the feeling of awe and wonder that man can move so quickly in an environment which is not natural to him. As I flew over Baltimore and Phildelphia, two cities which I have learned to love, and saw the lights spread out below me, I was moved to pride that I could be one of the human race that had learned to do what man has done, that I was one who had the great new avenues open to me, along with countless others.

As I told my experience to another and my emotions of that evening, he replied, "And how did you feel when you motored through the slums of New York? How would you have felt had you motored through the slums of Philadelphia or Baltimore on your way to your home?"

And I thought of the great gap between what we can do, as man has done in the achievement of human flight, and how little we have done in the creation of a better way of life. But I could not feel that way for long because I could not escape the realization that there is throughout our cities hidden beneath the slums, hidden beneath what seems to be a sordid life, a true spirit of vitality.

There is, I believe, more vitality in our lives, more noble endeavor, more vision and courage than we are apt to think. Throughout recorded history adventurous voyagers and our own pioneering fathers fired imagination and broadened the spirit of man.

The opportunities for geographical exploration are less rich than

they once were, with all regard for Jim Van Allen and other explorers of outer space. But the explorations of nature are now more possible than they were before, and it is this spirit of those explorations which gives vitality to life, which gives me heart to believe that the lives we live will be even better.

The need for knowledge is great and urgent because man has vast new powers with which he can change his surroundings and the pattern of his life quickly, wisely or unwisely; and the hope is there that the knowledge that can be gained is without limit.

During the course of centuries man lived in an environment which changed slowly except in times of catastrophe. That is no longer true. By the use of scientific knowledge men can now alter their surroundings rapidly and radically. They can move quickly from environments in which man has lived for countless centuries into environments in which man has never lived before. Man can make his environment what he will.

Our early ancestors lived in caves and slowly moved into rude huts and cold houses of rough hewn stone and timber. For countless centuries our ancestors warmed themselves before open fires, and then within a short century man has learned to build for himself towering structures in which he is surrounded by the temperature and light he chooses. Throughout recorded history and until a century ago men moved only on their own legs. They gradually learned to travel a little faster and more easily by harnessing animals to carts on skids or wheels, and boats were ultimately propelled by the force of wind on sails. In the space of a short century and a half man has increased his speed of travel from no more than he could run to greater than the velocity of sound. His environment can encompass the globe within a few short days.

Throughout history there is recorded man's envious desire to fly like birds. Each present day countless thousands fly faster than birds at altitudes where oxygen for life is lacking.

Man suited his life to his natural surroundings and lived in close association with countless other living creatures. Only slowly did he find the means for changing the world as he found it. Laboriously he cleared the forests with his ax, drained the swamps with hand dug ditches, hunted wild beasts and endured the insects. Now, within a few short years, he has learned how to fell with chainsaws trees across denuded acres. Bulldozers change the earth's configuration and chemical insecticides quickly alter the pattern of the fauna.

Our increasing power to change the physical world around us, to build things and create new patterns of life, is due in large part to our machines. They are so numerous and powerful that we seldom think of them as the evolutionary development of the human organism, but that they are. They give to little men the leashed power of a million horses. They carry us to distant places in a brief period of time and

even our words are spread to far reaches, although the words still come from our own lungs and vocal cords.

It is the human mind that has enabled us to add the power of machines to the natural power of our bodies, for machines are but the creation of man's mind. The mind also does more through science. It creates instruments which extend its own powers. The steel yard of Roman times and the modern microbalance have enabled man to comprehend the weight of things. Through microscopes we see what cannot be seen by the unaided eye and brain. Telescopes and rockets extend our vision and imagination to the distant reaches of the universe. Electronic computers increase our ability to perform mental operations.

The mind supported by scientific knowledge and instruments has explored the nature of man himself. Electronic amplifiers disclose the condition of the heart and the mysterious workings of the brain. The electron microscope brings viruses within our range of vision. Man-made radioactive elements trace the chemical processes of life.

Such greater understanding of man is timely for the suitability of machines and man-made enviornments is limited by the characteristics of the human body. The healthy progress of our scientific civilization requires that the human significance of machines be recognized lest great powers be inadequately controlled or the body be subjected to unfavorable conditions which overtax its capacity for adaptation.

If instruments and machines and chemical products of industry are to satisfy the needs of man, they must be designed to meet the biological requirements of the user. We are still human beings. Even though our powers have been greatly increased, we must learn to live as a part of the totality of life, the environment in which life has always been required to exist.

Our new and awesome powers make urgent the advice of Francis Bacon which Benjamin Franklin so often quoted: "He who would master nature must obey her laws. He must learn her laws and then obey them."

The desire for understanding may not seem to be adequate justification for public support of curious scientists, although it is now a common practice. But I would point out that the justification was given by a wise poet of another age. He gave it as an enduring challenge from the Lord. In the Book of Job it is recorded:

"Then the Lord spoke to Job out of the whirlwind, and said: Gird up now thy loins like a man; For I will demand of thee that thou hast understanding."

Not all who see an apple fall can form an architectonic concept cosmic in its scope and grandeur as did Isaac Newton, but every man can have a deeper understanding of the significance and implications of science and through the quest for understanding reach the greater dignity of human life.

Because I have so long been a resident of the City of Philadelphia

I have always been impressed how in the days of Benjamin Franklin there was a widespread interest in science. To quote Dean Nichols of the University of Pennsylvania: "The Philadelphians of the 18th century were engaged in discussing electricity, gravity, the transit of Venus and other questions in basic science which did not have much immediate application, but because they wanted to satisfy their curiosity. Basic science was something of a community project eliciting general interest."

Dean Nichols goes on to say: "Scientists must be more anxious to excite the imagination, the curiosity and the hope of a somewhat frightened society. The times demand an effort to show the community the values which may be conserved and insured by adequately supported programs in basic science."

Our fellowmen by and large are only dazzled by the extent and complexity of our knowledge. They have too little comprehension of the extent of what we do not know and the meaning of what we do. This, I take it, is one of the great implications of your program of education carried out here at The Franklin Institute.

If science is giving us various powers which can be used wisely or unwisely, if science is a great spiritual undertaking of man, if science can give hope and inspiration to all people, then all people must have a greater understanding not only of the facts of science but of its spirit and its implications.

There are times when the boundaries of human experience which are usually narrow and fluctuate but little between age and age suddenly widen, and the spirit of man leaps forward to possess and explore its new domain. Those are the great ages of the world. They were the ages of Pericles in Athens, the age when Europe passed from what we call the Dark to what we call the Middle Ages, the Renaissance and the period of the French Revolution.

The present period in which man is possessed of new forces and new extensions to his senses, of new mental powers with which to seek knowledge and shape the pattern and environment of his life, and the spirit of going forward as only man can go in gaining greater understanding, could be another of the great ages of the world, or it could be the catastrophic last.

From the great adventures of the human mind on the frontiers of knowledge come the building stones of a better world, but the world will be as we choose to make it.

As I say those closing words I am reminded of one of the last times I talked with Dag Hammarskjold. The times were not cheerful nor hopeful, but he with his characteristic faith in the reasonableness of man, based upon understanding, based upon that which is the true spirit of the scientist and all who seek understanding, said, "We will not fail with courage for our shield and intelligence as our weapon."

BOOK REVIEWS

PHOTOCHEMISTRY OF AIR POLLUTION, by Philip A. Leighton. 278 pages, diagrams, illustrations, 6 × 9 in. New York, Academic Press, Inc., 1961. Price, $11.00.

Postulation and elucidation of the mechanism of photochemical reactions in air pollution chemistry is only about a decade old. Advances have been rapid with new developments coming on the heels of earlier work usually before general publication. This has been possible because relatively few research centers were involved and liaison between investigators has been excellent. This field has not reached a state of development where a fairly definitive treatise could be issued as the final word. On the other hand, some compilation of knowledge has been needed.

Photochemistry of Air Pollution is a new, up-to-date treatment of a newly-opened branch of chemistry. The editorial style is that of a critical review with liberal interpretation of conflicting results and enumeration of areas requiring further study. Organization in ten chapters includes discussion of solar radiation, primary and secondary reactions, and reactions with oxygen atoms, ozone, oxides and oxy acids of nitrogen, free radicals, and sulfur dioxide. Dr. Leighton has succeeded in abstracting the best from 456 references and liberally cross-references all chemical reactions and conclusions. This is an accomplishment which only his contemporaries will fully appreciate.

The book is best suited for the graduate chemist or engineer familiar with basic organic chemistry and possessing at least a modicum of knowledge of the spectrographic and chromatographic instrumental analytical procedures. Many portions of the well-edited text assume a priori knowledge of air pollution problems or the importance of specific substances. Consequently it is not recommended as a primer on air pollution chemistry. The book will be valuable to all researchers, university lecturers, and technical personnel concerned with phytotoxicity, aerosol formation, eye irritation and other physiological effects, and basic photochemical reactions of air pollution.

Individual chapters are closed by a summary of the preceding material. The best summarization is that of chapter III, Absorption Rates and Primary Photochemical Processes. Tabular presentation of products of photochemical processes and the processes are included. Future editions would benefit by expansion of the introductory chapter and the summary sections of some of the chapters. Such expansion would increase the potential usefulness to students and technical personnel unacquainted with the subject. Because of the nature of the subject and the rate of new developments, it is this reviewer's hope that Dr. Leighton will periodically update the material by new editions.

ROBERT A. BAKER
The Franklin Institute Laboratories

GAMES OF STRATEGY: THEORY AND APPLICATIONS, by Melvin Dresher. 178 pages, diagrams, 6 × 9 in. Englewood Cliffs (N.J.), Prentice-Hall, Inc., 1961. Price: $6.75 (text); $9.00 (trade).

This book is primarily a treatise on the solutions of certain games of strategy and the methods which have been used in arriving at them. The author limits his coverage to two person games. His aim is to "develop the subject matter in such a way as to make the volume adaptable as a text on the theory of games in colleges and universities." However, his approach in most of the chapters dealing with the theory behind the methods of solution is not nearly so carefully or rigorously done as in the chapters dealing with specific games. There are many spots where portions of proofs are sloughed over as obvious or unimportant but where a student could be helped with a little more rigor or motivation behind the proof. On the other hand many specific games (almost solely of a military nature) are worked out quite fully, often in the manner of individual technical papers. The results of these and other games whose

solutions are just given are of interest to specialists in the field who might be interested in these games. However, it appears to the reviewer that the emphasis is wrong for students who would not be helped by lists of solutions to particular games.

The book covers the following specific material:

1) The basic definitions of two person games in closed and extensive form—mixed and pure strategies, optimal strategies, solutions, etc.

2) A proof of the fundamental theorem—the minimax theorem—by constructing a solution by the well-known simplex method (here some motivation for the student is sorely needed).

3) Properties of optimal strategies (this chapter had a number of errors in it, both misprints and otherwise).

4) Methods of solving games (an interesting and well written chapter in which the proper use of illustrative examples clarifies the method of attack).

5) Definitions and solutions of infinite games (i.e., games with an infinite number of strategies) with a full chapter on games with convex payoff functions and another on games with separable payoff functions.

6) Two chapters on special games—Games of Timing (Duels) and a Tactical Air-War Game.

On the whole, for methods of solutions, especially for particular games, this book illustrates some interesting techniques. For researchers or users of those particular games it is of interest. For students, however, the approach is wrong. Also throughout the book there are misprints and errors that should have been caught in the proof-reading. These were somewhat distracting in the reading of the book.

HERBERT M. GURK
Radio Corporation of America

PLASMAS AND CONTROLLED FUSION, by David J. Rose and Melville Clark, Jr. 462 pages, diagrams, illustrations, 6 × 9 in. Cambridge, The M.I.T. Press; New York, John Wiley & Sons, Inc., 1961. Price, $10.75.

As described on the jacket, this book is intended for a two-semester graduate course on the basic principles of this highly timely subject. Both authors are professors of nucleonic engineering at M.I.T. The subject of Plasmas is, of course, of interest in several modern scientific and technological fields among which is the direct conversion of heat into electrical energy.

As regards Controlled Fusion, one has a technological field in which great effort is being expended and a considerable literature exists before the achievement of a single case of practical success. This state of affairs is of course fully justified by the terrible urgency and fantastic potentialities of this form of energy production. In the introductory chapter it is estimated that the world's supply of conventional fuels, making what the authors consider to be liberal estimates for already undiscovered reserves, will be exhausted in about 100 years. The availability of nuclear energy from fissionable materials such as uranium and thorium by techniques which are now known to be feasible will make the situation somewhat less worrisome for our grandchildren but will not last for a great many more generations thereafter. Contrasting with this the amount of available deuterium, which is the fuel for the fusion process, would last 10^9 years. Such a time would seem to be sufficient to allay anxiety!

But the problem is how to do it. In broad outline there appears to be a way in which the problem can be solved; the technical problems are, however, of great magnitude. The book outlines these problems systematically and presents in highly readable fashion the fundamental materials required for the solution.

Stated as simply as possible, a device is required which will cause deuterium and tritium nuclei to be thrown at each other with energies sufficient to overcome their Coulomb repulsion. When this is done a nuclear compound is formed; energy is emitted in the form of fast neutrons and the heat which appears when these neutrons are slowed down is used for practical purposes. The way to do this is to create a mixture of the two gases and maintain it at a temperature greater or exceeding that which exists in the interior of stars. Naturally, no material vessel can be used to contain this gas, which is completely ionized and is called a plasma; consequently it must be confined to its reacting region by means of magnetic and electric fields. This

region is then to be surrounded by material for slowing down the neutrons and thereby extracting the reaction energy.

The contents of the book therefore cover many aspects of atomic theory and mathematical physics. Collision phenomena, electrodynamics, and a peculiarly modern term which this subject has given birth to, hydromagnetics. The last three chapters are concerned with considerations relative to the three principal methods of confining the plasma to the reaction region. In addition to its high quality as a text, this book is recommended to any physicists in other fields who desire to acquaint themselves with the broad features of this topic.

W. E. DANFORTH
Bartol Research Foundation

MOLECULAR SIEVES, by Charles K. Hersh. 122 pages, diagrams, illustrations, 6 × 9 in. New York, Reinhold Publishing Corp., 1961. Price, $6.50.

Molecular sieves are important since they permit gaseous separation based on molecular size. The book, *Molecular Sieves*, is a short and interesting discussion of these substances. It treats the nature and use of naturally occurring zeolites and crystalline aluminosilicates with major emphasis on the latter because of their commercial importance.

A short, elementary discussion of the physical chemistry of adsorption precedes the chapters on the zeolites and sieves. This will be very welcomed by the lab technicians. Subsequent chapters describe the important natural zeolites (such as the Chabazite, a cubic zeolite and effective water adsorber) and the commercial Linde and Grace aluminosilicates. Availability, properties, adsorptive capacity, selective separation, regeneration, kinetics, test and design data are reviewed.

The final chapter describes "other uses" and gives some interesting applications of an exotic nature as well as very practical suggestions. One example typifies the latter case and also demonstrates an annoying aspect of this little book: Use of type 5A molecular sieves in gas chromatography for separation of nitric oxide and nitrous oxide is mentioned. This interests many chemists but no bibliographic reference is noted. This is the case throughout. There are four pages of bibliography compiled under broad topics at the end of the book. These are not referenced to the text and even titles of the publications, except for books, are omitted. The user of the book would have certainly benefited from a little extra devotion to this bibliography.

Molecular Sieves is an easy-to-read book that chemists, chemical engineers and other technical personnel involved in adsorption will find useful.

ROBERT A. BAKER
The Franklin Institute Laboratories

THEORY OF HYDRODYNAMIC LUBRICATION, by Oscar Pinkus and Beno Sternlicht. 458 pages, diagrams, illustrations, 6½ × 9½ in. New York, McGraw-Hill Book Co., Inc., 1961. Price, $15.00.

Although fluid film lubrication is centuries old, it was not until the last twenty years that the theory of hydrodynamic lubrication and its application have received popularity as a field of scientific endeavor. This interest was due in part to increased industrial use of film bearings and the demands for reliable design. An added growth stimulus was the availability of digital computers and the development of numerical techniques which made possible the solution of current problems. Thus to the art of lubrication was added the science of lubrication. Many technical papers are available on this subject, but unfortunately this literary profusion does not present a unified and ordered picture of the theory of hydrodynamic lubrication. Through its systematic presentation of material, this book alleviates that condition and contributes to our understanding of fluid films.

The authors' purpose is threefold: to state the basic differential equations, to show methods of obtaining solutions, and to give solutions when they are obtainable. These objectives have been met in a commendable fashion. The source of much material has been the published papers of engineering societies although some unpublished work of the authors is included. The material is presented in a well-ordered sequence, the mathematical operations are somewhat expeditiously treated in deference to the subject material, and the book has been unified with a standardization of symbols.

The authors first derive the basic differential equations for fluid films. The remaining portion of the book is primarily the application of these equations to the study of journal, slider, and thrust bearings. Both infinite and finite bearings are considered. Closed form solutions are presented when obtainable, otherwise graphical or tabular information is supplied. Incompressible and compressible lubricants are treated, turbulence and inertia effects are considered as are bearing stability, surface deformation, and non-Newtonian flow. Material on hydrostatic bearings is also included. A chapter is devoted to extending the limits of the classical theory to include thick film regions and the final chapter presents experimental evidence showing the adequacy of the analytical models and of the theoretical solutions.

Although a minimum of space has been allocated to the mathematics involved in this highly analytical field, the book still remains largely mathematical in nature. In spite of the fact that comprehensive tables of design data are included in the text, the volume will undoubtedly be more acceptable to those whose bent is for analysis rather than to those whose interests are basically design. A familiarity with ordinary differential equations is necessary and with partial differential equations is desirable if the book is to be appreciated to the fullest extent.

The appearance of this volume is timely and its coverage of both basic fundamentals and recent developments in hydrodynamic lubrication theory is thorough.

DONALD F. HAYS
General Motors Research Laboratories

THERMOELECTRICITY: SCIENCE AND ENGINEERING, by Robert R. Heikes and Roland W. Ure, Jr. 576 pages, diagrams, 6 × 9 in. New York, Interscience Publishers, Inc., 1961. Price, $18.50.

If the writing of books on current research at times marks the arrival of an integral understanding, it is no less as often the telltale sign of momentary paralysis. Such may seem appropriate to diagnose the commerical product of thermoelectric research—the figure of merit or efficiency index of available materials. "Thermoelectricity: Science and Engineering" is not the coroner's report. In its presentation of theory, approximation, result, and anomaly it reviews the remarkable, recent progress of thermoelectricity and pieces together in its 17 chapters a composite picture of the ignorance waylaid in the pursuit and the complexity of the task that remains.

Some one hundred and forty years have passed since Seebeck first announced the effect which, until recently, was exploited only in the (thermocouple) measurement of temperature. In this country the major renaissance of thermoelectricity following World War II has placed the Seebeck and Peltier effects in the category of advanced energy conversion schemes. The stimulus of early success in the search for better materials was to become, in part, a stigma (patent applications for some best present day materials have been on file for 5 years) but the progress toward the understanding of the solid state behavior has continued almost uninterrupted to the present.

All contributions to this volume have come from the staff of the Westinghouse Research Laboratories through work done prinicpally under a Navy contract. The early chapters comprise introductory remarks, the thermodynamic statements of the thermoelectric parameters, and the derivation of the pertinent transport properties for semiconductors and other materials of possible interest. Thermal conductivity and the chemistry of mixed valence materials are discussed in separate chapters. Radiation effects and diffusion, on which the useful life of a thermoelement may depend, are treated in two chapters although much of the experimental work reviewed pertains, necessarily, to materials not of thermoelectric interest. The chapter on crystal growth, and the measurement, theory and survey of thermoelectric materials constitute the central theme of much research done today. Unfortunately, the review of some recent work describing the effects on the transport parameters of freezing conditions, inhomogeneity, and the presence of a second phase was precluded by the publication date. Separate chapters are awarded to low temperature Peltier cooling which, despite its utility, has received little attention until recently, and also to thermionic conversion as the high temperature complement to thermoelectricity for power conversion. Device performance and some associated problems are

covered in the final three chapters in a manner not oblivious to the ignorance, here, of the reader most readily attracted to this book.

Although much of the contents is a review of published work, some new contributions are indicated in the preface. Among these are discussions of narrow band semiconductors, and monographs for determining the maximum figure of merit from an arbitrary set of thermoelectric parameters subject to certain assumptions.

Compared to similar compilations of recent work in thermoelectricity (viz., the volumes edited by I. Cadoff and E. Miller, and P. Egli) this book emerges, distinctly, as the best compromise between detail and integrity though for the sake of the former what is sacrificed in the latter may make the purchase of the deceptively titled but succinct little volume by H. J. Goldsmid ("Applications of Thermoelectricity," Methuen Ltd., London, 1960) the best buy for the new entrants into this field.

Notwithstanding the large contributions by the principal authors, this effort taken as a whole illustrates the necessity of merging disciplined specialities in a new area of research already too large to be approached with either small ideas or a small budget.

LOUIS R. TESTARDI
The Franklin Institute Laboratories

FILTRATION, by George D. Dickey. 353 pages, diagrams, illustrations, 6 × 9 in. New York, Reinhold Publishing Corp., 1961. Price, $12.00.

There has been a recent vogue, usually justified, to select specific chemical engineering unit operations for more detailed treatment. It is generally expected that these treatises will be complete, covering the pertinent theoretical and applications aspects of the subject.

Filtration emphasizes one-half of the subject-applications. Of fifteen chapters, only one of ten pages is devoted to theory. This is wholly inadequate. This seems to be the case for most filtration discussions and yet the evaluation of filtration performance can properly only be made by application of those theoretical-mathematical relationships so often bypassed.

Filtration delves into considerable history and presents drawings and sketches of ancient filters and applications. This devotion to the past is hard to reconcile with the author's implication that a more thorough theoretical treatment is out-of-order because of space and scope. There are many cuts of modern filtration devices for pictorial explanation of the easy-to-read often homey text. For example, in the chapter on Vacuum Filtration it is noted that difficulties occur when workmen leave tools on the top filter flanges. These fall into the tank and jam agitators. There is also comment that when filtration performance is effected by filter plugging, the chemical engineer wishes he knew more about colloidal chemistry. There are many operating pointers that indicate the author's thorough comprehension of the "practical" problems of filtration.

For those interested or concerned with the history or the operator's viewpoint of filtration this book may be helpful. Those wishing to develop or apply various correlations and performance evaluation will be most disappointed.

ROBERT A. BAKER
The Franklin Institute Laboratories

BOOK NOTES

LINEAR VACUUM-TUBE AND TRANSISTOR CIRCUITS, by Alfred J. Cote, Jr. and J. Barry Oakes. 402 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1961. Price, $10.75.

This text treats only linear active circuits using terminology (two-port) which is significant in circuit design rather than in device design. The two-port theory (discussed in chapter 2) is the foundation upon which the authors base their unified approach. After relating equivalent-circuit device parameters to active-network circuit parameters (in Chapter 3), the authors then treat effects of frequency, passive two-port networks, cascaded stages, bandpass cascades, feedback configurations, feedback oscillators, two-port stability and power gain, and matrix analysis of networks.

DESIGN MANUAL FOR TRANSISTOR CIRCUITS, edited by John M. Carroll. 376 pages, diagrams, illustrations, 8 × 11 in. New York, McGraw-Hill Book Co., Inc., 1961. Price, $9.50.

This manual offers a collection of tested transistor circuits which design engineers may adapt to a variety of individual applications. The first chapter reviews fundamentals of semiconductor devices; the next two chapters cover circuit design techniques and charts. The remaining eighteen chapters deal with circuits for specific applications, for example, amplifiers, radio and TV receivers, test instruments, servomechanisms, medical instruments, telemetry for missiles and satellites, guidance systems in missiles and aircraft, and computers. The articles for the most part have been adapted from ones appearing in *Electronics*.

PRINCIPLES OF REFRIGERATION, by Roy J. Dossat. 534 pages, diagrams, illustrations, 7 × 9½ in. New York, John Wiley & Sons, Inc., 1961. Price, $11.50.

The author, at present an Associate Professor of Refrigeration and Air Conditioning at the University of Houston, has done consulting work for several firms and has established training programs for various refrigeration and air conditioning dealer organizations.

Throughout this textbook, emphasis is placed on the cyclic nature of the refrigeration system, with each part of the system carefully examined in relation to the whole. Care is taken to correlate theory and practice through the use of manufacturer's catalog data and sample problems.

The first four chapters deal with the fundamental principles of physics and thermodynamics upon which the refrigeration cycle is based. These chapters could serve as review or reference material for those who are already familiar with these fundamentals. Chapter 21 treats electric motors and control circuits as they apply to refrigeration and air conditioning systems. The more mathematical approach has been left to companion electrical courses, with this material being presented from the viewpoint of practical application.

Approximately 100 pages of tables and charts are included at the end of the text.

HANDBUCH DER PHYSIK, Band XI/1, Akustik I, edited by S. Flügge. 417 pages, diagrams, illustrations, 7 × 10 in. Berlin, Springer-Verlag, 1961. Price, DM 128.

This volume of the monumental *Handbuch* contains five contributions—three in English, two in German. Philip Morse and K. Uno Ingard discuss "Linear Acoustic Theory," including basic concepts and formulas, and the behavior of simple and coupled acoustic systems. Hans Kneser's paper, "Schallabsorption und -dispersion in Gasen," covers theory, continuum mechanics, kinetic theory, experimental methods and results, and the relaxation theory. Konrad Tamm, in "Schallabsorption und -dispersion in wäbrigen Elektrolytlösungen," discusses relaxation theory as applied to aqueous electrolytic solutions, methods of measurement, sound absorption in electrolytic solutions, and gives an interpretation of absorption in electrolytic solutions.

"Dispersion and Absorption of Sound Waves in Liquids and Mixtures of Liquids," by Daniele Sette, treats in detail such theories as visco-thermal theory, relaxation in liquids, visco-elasticity, and special effects (shear and transverse waves), and discusses experimental results and methods. The final contribution, "Dispersion and Absorption of Sound in High Polymers," by Warren Mason, deals with phenomenological methods for characterizing relaxations, special measuring instruments for measuring the properties of polymers, long chain polymer molecules in solutions, properties of polymer liquids, and elastic properties of polymer solids. The German-English and English-German indices complete the book.

PROBLEMS IN QUANTUM MECHANICS, by I. I. Gol'dman and V. D. Krivchenkov, translated from the Russian by E. Marquit and E. Lepa. 268 pages, diagrams, 6 × 9 in. Reading (Mass.), Addison-Wesley Publishing Co., Inc., 1961. Price, $8.50.

This is a comprehensive collection of problems in nonrelativistic quantum mechanics, with answers and completely worked-out solutions. Although designed primarily for use with Landau and Lifshitz' *Quantum Mechanics —Nonrelativistic Theory*, the book can profitably be used with any textbook in quantum mechanics. Perturbation matrices and their diagonalization are thoroughly covered. The problems are of varying degrees of difficulty.

MANAGEMENT GAMES, by Joel M. Kibbee, Clifford J. Craft and Burt Nanus. 312 pages, diagrams, 6 × 9 in. New York, Reinhold Publishing Corp., 1961. Price, $10.00.

Management games are one of the newest techniques used in training executives in the necessary and vital decision-making which management faces. These games provide training without involvement of capital, factories and staff. This book, after an introductory chapter on the theory and practice of management games, discusses the administration of such games, their design, and, finally, gives six case histories in varied fields. Treatment is nontechnical, and should interest management people, training specialists, educators, and those in the computer field.

THE RARE EARTHS, edited by F. H. Spedding and A. H. Daane. 641 pages, diagrams, illustrations, 6 × 9¼ in. New York, John Wiley & Sons, Inc., 1961. Price, $14.75.

Increasing interest in the "rare" earths (plus lanthanum, yttrium, and scandium) as a practically untapped source of new metals prompted the American Society of Metals to sponsor a symposium on the subject, held in 1959. This volume is the published proceedings of that symposium. Twenty-four papers are divided into four general sections: Occurrence and Extraction of Rare Earths (5 papers); Preparation of Rare-Earth Metals (7 papers); Properties of Rare-Earth Metals and Alloys (6 papers); and Applications of Rare-Earth Metals and Compounds (6 papers).

RADIATION CHEMISTRY OF GASES, by S. C. Lind. ACS Monograph No. 151, 313 pages, diagrams, illustrations, 6 × 9 in. New York, Reinhold Publishing Corp., 1961. Price, $12.50.

This monograph, a revised and greatly enlarged version of ACS Monograph No. 2 (1928), is restricted to gaseous systems in which ionizing radiation is used to effect chemical reactions. The first five chapters (Part I on Physical Principles) cover: introductory material; absorption; alpha-particles; sources such as gamma-rays, X-rays, Beta emitters, and nuclear reactors; and the kinetics of chemical reactions induced by radon. A section on dosimetry of water and of aqueous solution is included in Chapter 4. Part II consists of ten chapters on experimental work on gaseous reactions. These include oxidation, hydrogenation, polymerization, synthesis and decomposition of nitrogen oxides, radiation chemistry in electrical fields, etc. Both organic and inorganic chemists will find material of interest in this comprehensive treatment.

HANDBUCH DER PHYSIK, BAND XLVI/1, KOSMISCHE STRAHLUNG I, edited by S. Flügge. 315 pages, diagrams, illustrations, 7 × 10 in. Berlin, Springer-Verlag, 1961. Price, DM 98.

Six contributions comprise this volume of the authoritative *Handbuch der Physik*. Al-

though all are in English, the authors are from the United States, Mexico, Israel and Great Britain. The first paper (by Philip Morrison) discusses "The Origin of Cosmic Rays," including structure and synthesis of a model, the propagation of cosmic-ray beams, and the diffusion of cosmic-ray particles. "Theory of the Geomagnetic Effects of Cosmic Radiation" (by Manuel Vallarta) develops the theory of the allowed cone, discusses asymptotic and periodic orbits, trajectories, and the geomagnetic energy cut-off (resulting from his theory). "Experimental Results of Flights in the Stratosphere" (by Ernest Ray) is a short paper summarizing recent data gathered by balloon, airplane and rockets. "Penetrating Showers" (by Kurt Sitte) interprets attenuation and interaction mean free path of the shower particles, and meson production in penetrating showers. "Extensive Showers" (by Guiseppe Cocconi) discusses the electromagnetic cascade (both theory and experimental results), the meson-nucleon cascade (experimental results with the μ- and N-components), and time variations of primary radiations. The final treatise, "The Hard Components of μ-Mesons in the Atmosphere" (by Gerald Fowler and Arnold Wolfendale) treats properties of the μ-meson component in the vertical direction (including effects of instrumental bias and latitude) and in inclined directions (including latitude effect and positive excess). Authoritative and comprehensive, this volume will be particularly useful to scientists who speak and read only English.

PRINCIPLES OF LINEAR NETWORKS, by Bernard Friedland, Omar Wing and Robert Ash. 266 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1961. Price, $8.95.

An introductory text, this new book covers the usual subject matter for electric circuit texts. The difference between this text and the majority of others is that it is aimed at students with more than two years of mathematics and three semesters of physics. Thus, much expository material normally included in electric circuit texts has been omitted or only lightly touched upon. The nine chapters are: Fundamentals; Circuit Elements; Basic Principles of Network Analysis; Independent Network Equations; Nodal and Loop Analysis; Elementary Transient Analysis; Networks in the Sinusoidal Steady State; Frequency Characteristics of Networks; and Two-Terminal-Pair Networks. The order of presentation, as noted from the above chapter titles, differs from the customary order.

HANDBUCH DER PHYSIK, Band XXV/1, Kristalloptik—Diffraction, edited by S. Flügge. 573 pages, diagrams, illustrations, 7 × 10 in. Berlin, Springer-Verlag, 1961. Price, DM 168.

Only two papers—one in English, one in German—are included in this volume of the *Handbuch*. G. N. Ramachandran and S. Ramaseshan cover "Crystal Optics" quite thoroughly in a 218-page paper. Beginning with a discussion of the polarization of light, the authors proceed to the theory of propagation of light in anisotropic media (for non-absorbing and absorbing, active and non-active crystals), optical phenomena in crystalline media (refraction, reflection, interference phenomena, birefringent plates), experimental techniques, and the variation of properties due to external influences. H. Höno, A. W. Maue and K. Westpfahl, in their paper in "Theorie der Beugung," begin with a section on general methods. In this section, they include heuristic methods (Kirchhoff's, the iteration techniques of Franz and Braunbek, and Keller's geometric theory), the theory of integral equations (for example, boundary value problems, scalar and vector problems, scattering and transmission). The second part of the paper discusses at length two classes of special problems in diffraction: first, for plane surfaces, and second, for convex bodies.

PROTECTIVE CONSTRUCTION IN A NUCLEAR AGE (Proceedings of the Second Protective Construction Symposium), edited by J. J. O'Sullivan. Vols. I and II, 884 pages, diagrams, illustrations, 8 × 10 in. New York, The Macmillan Co., 1961. Price, $25.00 for the set.

This two-volume proceedings of the Second Protective Construction Symposium would have been more useful had it been published more quickly. The symposium, held in

March, 1959, was intended not only to define the problems engineers would face in designing deep underground civilian shelters, but also to delineate political problems and weapons technology. Since the purpose was to "stimulate new creative thinking on this vital subject," the 2½-year publication delay means that designers have been denied access to information which might have saved them a lot of time and work. Among the topics included are site selection, design of exposed items such as ventilation openings, utilities for underground installations (power supplies, etc.), new construction methods (drilling, excavation, etc.) and underground phenomena of nuclear bursts. There are 45 papers in the two volumes.

PROGRAMMING AND CODING FOR DIGITAL COMPUTERS, by George W. Evans, II and Clay L. Perry. 233 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1961. Price, $9.50.

The rapidly expanding use of the digital computer as a research tool and a production tool makes it imperative to have books on systematic approaches to such phases of digital computer operation as problem formulation, selection of numerical methods, programming and coding, and computer operation.

The present volume devotes itself to the programming and coding phase, based on the use of the von Neumann flow chart. It can either be used as a junior-year college text or by people working with digital computers. Eleven chapters cover such topics as basic concepts, coding with *B*-boxes, subroutines, magnetic tape units, numerical analysis, and automatic programming.

NUMERICAL WEATHER ANALYSIS AND PREDICTION, by Philip D. Thompson. 163 pages, diagrams, 6¼ × 9¼ in. New York, The Macmillan Co., 1961. Price, $6.50.

The first book on weather forecasting by means of high-speed automatic digital computers, this small volume emphasizes basic theoretical and computing problems. These new techniques are important for jet plane transportation, missile and satellite launching, as well as for daily public weather forecasting. The author has aimed his book at two audiences—graduate meteorology students and persons with a general background in mathematics and physics. Consequently, numerical rather than analytic methods are emphasized. The author treats such topics as sound, gravity and Rossby waves, the filtering problem, the equivalent-baratropic model, baroclinic instability, and errors and unsolved problems.

PROGRAMMING COMPUTERS FOR BUSINESS APPLICATIONS, by Ned Chapin. 231 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1961. Price, $7.50.

A practical guide, this book takes you to the core of programming to show you the kind of thinking the programmer must do to obtain maximum efficiency in programming and coding. After presenting a solid foundation of basic data, the text proceeds to more advanced discussions for those who want to know more about the latest data processing techniques.

Full coverage is given such pertinent areas as sorting, reruns, buffer use, timing, random access, and interrupt programming. The author provides exercises and diagrams to complement the textual material. A highly-advanced mathematical background is not necessary to use this guide successfully.

The author's manner of presentation, along with comprehensive appendices, helps make the book easily understandable by both beginners and advanced practitioners.

PROBABILITY AND EXPERIMENTAL ERRORS IN SCIENCE, by Lyman G. Parratt. 237 pages, diagrams, 6 × 9 in. New York, John Wiley & Sons, Inc., 1961. Price, $7.25.

Written by a man who is an experienced teacher and a distinguished physical scientist, this book fully clarifies the relationship of statistics and probability theory to problems in, as well as the philosophy of, modern physical science. At the same time, it teaches the mechanics involved in applying proper formulas to scientific situations.

While primary emphasis is given to the experimental definitions of probability, the classical is also covered. Classical games of chance are introduced early in the book in

order to arouse the reader's interest and help him develop his feeling for probability into quantitative concepts. The discussion then shifts to measurements in science and to general statistical concepts, such as maximum likelihood, curve fitting, and consistency tests. The normal (Gauss) and the Poisson models of mathematical probability are explored both analytically and through typical problems.

Numerous problems are included, some with answers.

SYSTEMS: RESEARCH AND DESIGN (Proceedings of The First Systems Symposium at Case Institute of Technology), edited by Donald P. Eckman. 308 pages, diagrams, illustrations, 6 × 9 in. New York, John Wiley & Sons, Inc., 1961. Price, $8.50.

This book is composed of a collection of papers presented at Case Institute of Technology's First Systems Symposium in April, 1960 at Cleveland, Ohio.

Some of the chapters are "Systems, Organizations, and Interdisciplinary Research" by Russell L. Ackoff, "A Problem in theDesign of Large-Scale Digital Computer Systems" by R. J. Nelson, "In Search of Quantifiable Parameters of Group Performance" by A. Rapoport, "On Identification and Evaluation of the Transfer Dynamics of Physical Systems" by E. Mishkin and J. G. Truxal, and "Systems Engineering from an Industrial Viewpoint" by H. Chestnut.

REFRACTORY METALS AND ALLOYS, Vol. 11 of Metallurgical Society Conferences, edited by N. Semchyshen and J. J. Harwood. 617 pages, diagrams, illustrations, 6 × 9 in. New York, Interscience Publishers, Inc., 1961. Price, $22.00.

The Proceedings of the Symposium on Refractory Metals and Alloys, held at the McGregor Memorial Center, Wayne State University, Detroit, Michigan, May 25–26, 1960, are presented in this volume.

The format of the book is arranged in a similar manner as the conference presentations and the subject matter is treated in three sections. Considered first are the general metallurgical features of the refractory metals and alloys, as a group, to delineate both the common aspects and the striking differences existing among the individual systems with respect to alloying behavior, flow and fracture phenomena, strengthening mechanisms, and oxidation and surface reactivity.

Presented in more detail in the second section are the metallurgical characteristics and features of the individual refractory metal systems. In the last section, the refractory metals are considered as a group with respect to their fabrication, engineering behavior, and current and proposed fields of applications.

In their preface, the editors state that "It was the aim of the Symposium and the intent of this volume to present definitive information concerning the advantages and disadvantages of the behavior and properties of the refractory metals as a group and as competitive individuals."

PUBLICATIONS RECEIVED

ELECTRIC MACHINERY, by A. E. FitzGerald and Charles Kingsley, Jr. Second edition, 568 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1961. Price, $10.75.

MODERN MAGNETISM, by L. F. Bates. Fourth edition, 514 pages, diagrams, 5⅛ × 8 in. New York, Cambridge University Press, 1961. Price, $2.95 (paper).

SIMPLIFIED MECHANICS AND STRENGTH OF MATERIALS, by Harry Parker. Second edition, 285 pages, diagrams, 5 × 7¾ in. New York, John Wiley & Sons, Inc., 1961. Price, $6.75.

PROBLEMS IN APPLIED DESCRIPTIVE GEOMETRY, by Matthew McNeary. v.p., diagrams, 8½ × 11 in. New York, McGraw-Hill Book, Inc., 1961. Price, $3.95 (paper).

FUNDS FOR RESEARCH AND DEVELOPMENT IN INDUSTRY. 1958. 119 pages, diagrams, 8 × 10¼ in. Washington, U. S. Government Printing Office, 1961. Price, $0.65 (paper).

A GUIDE TO FORTRAN PROGRAMMING, by Daniel D. McCracken. 88 pages, diagrams, 8½ × 11 in. New York, John Wiley & Sons, Inc., 1961. Price, $2.95 (paper).

SPRING DESIGN AND APPLICATION, edited by Nicholas Chironis. 344 pages, diagrams, illustrations, 8¼ × 11 in. New York, McGraw-Hill Book Co., Inc., 1961. Price, $9.50.

SCIENCE AND MUSIC, by Sir James Jeans. 258 pages, diagrams, plates, 5 × 7½ in. Reissue of first edition. New York, Cambridge University Press, 1961. Price, $1.95 (paper).

INDUSTRIAL ELECTRONICS MADE EASY, by Tom Jaski. 288 pages, diagrams, illustrations, 5½ × 8½ in. New York, Gernsback Library, Inc., 1961. Price: $5.95 (hard cover); $3.95 (paper).

REMEMBERING, by W. Von Leyden. 128 pages, 5½ × 8½ in. New York, Philosophical Library, 1961. Price, $4.75.

ERRATUM

K. S. Prasanna Kumar, co-author of "Statistical Design of Discrete-Data Control Systems Subject to Power Limitation" appearing in this JOURNAL for September, 1961, was erroneously identified. He is a member of the Control and Information Systems Laboratory, Purdue University, West Lafayette, Ind.

GROWTH OF METAL CRYSTALS FROM THE VAPOR PHASE

In a National Bureau of Standards program of fundamental research in metal physics, a study was recently made of the growth of zinc crystals from the vapor phase.[1] Growth rate data from experiments conducted by R. L. Parker and L. M. Kushner of the Bureau staff were found to be in good qualitative agreement with the screw dislocation theory[2] of crystal growth as modified by impurities, and to show no evidence of surface nucleation effects.[3] These results, among the first of this type to be obtained on monatomic systems, provide information on the mechanisms involved in the metallurgically important process of crystallization, and they will be of considerable value in other studies now under way on the growth kinetics of potassium crystals and of mercury "whiskers."

In the transformation of a metal from the vapor phase to a crystalline solid, the velocity of growth of the crystal surface depends on the driving force of vapor supersaturation. One theory[2] of this velocity-supersaturation dependence assumes that a screw dislocation emerges on the crystal surface to provide a monatomic step for continuous crystal growth at low supersaturations. In another theory,[3] new layers are started by the formation of two-dimensional nuclei on the surface of a completed layer as a result of spontaneous fluctuations in the surface density of adsorbed atoms, and relatively high vapor supersaturations are required to achieve this nucleation. In the present work to provide experimental data for the evaluation of these two theories, the growth rate of zinc crystals was investigated at low supersaturations (near equilibrium), since the rate predictions of the two concepts differ primarily in this area.

Zinc was chosen for the study because of its monatomic vapor, its high vapor pressure at convenient temperatures, and its availability in quite high purity (99.999+ per cent). In the experiments, the crystals were nucleated and grown in a Pyrex tube, about 13 cm long and 2.5 cm in diameter. A tungsten rod, sealed into one end of this "growth"

[1] For further technical details, see "Growth Rates of Zinc Crystals from the Vapor Phase," by R. L. Parker and L. M. Kushner, *J. Chem. Phys.*, Vol. 35, No. 4, Oct., 1961.

[2] "The Growth of Crystals and the Equilibrium Structure of Their Surfaces," by W. K. Burton, N. Cabrera and F. C. Frank, *Trans. Roy. Soc.* (*London*), Vol. 243, p. 299 (1951).

[3] "Kinetische Behandlung der Keimbildung in übersättigten Dämpfen," by R. Becker and W. Döring, *Ann. Phys.*, Vol. 24, p. 719 (1935).

tube, served as a cold tip on which nucleation and crystal formation could take place.

In preparing a tube for the experiments it was sealed, together with a Pyrex connecting tube containing approximately 10 grams of zinc, to a high vacuum system that previously had been outgassed for 18 hr. at 400°C. A portion of the connecting tube was then fitted inside an electric tubular furnace and heated to 400°C. When several grams of the zinc had distilled from this tube into the cold growth tube, the latter was sealed off from the vacuum system.

Growth rate measurements were obtained by inserting the growth tube into an apparatus which provided for continuous weighing of the crystal as it grew in supersaturated vapor. In this apparatus, consisting essentially of a large oven in which the proper temperature and supersaturation could be accurately maintained, the tube was mounted on a pivot above its center of gravity in such a manner that the end of the tube containing the tungsten rod tilted downward as the crystal grew. An automatic weighing device, activated by a photocell, was used to plot weight *vs* time on a recorder.

During the experiments, the growth tube was kept at a temperature T and the tungsten rod at a temperature $T_0 < T$ by means of a controlled heat leak fitted into the oven. The crystal was nucleated on the tungsten rod by gradually increasing the temperature difference ΔT. After nucleation occurred, ΔT was adjusted to a value which determined the vapor supersaturation σ, and the weight-*vs*-time measurements were recorded. This procedure was repeated at various ΔT values, and the weight-time information thus obtained was reduced to growth-velocity data.

The experiments showed that zinc crystals, in the form of truncated hexagonal pyramids, grow at supersaturations much less than the critical value established by the surface nucleation theory. Below this value, $\sigma_c \approx 0.8$, the theory predicts that growth virtually ceases. Furthermore, the nucleation upon the tungstent rod occurs at $\sigma \approx 0.02$ to 0.03, which is also much lower than expected from nucleation theory. However, when the experimental data were compared with the rate parameters of the screw dislocation theory, good agreement was found.

The effects of impurities on the growth rate were calculated from estimates of the rate of diffusion of water molecules (probably the major source of impurity) from the bulk of the Pyrex glass, and of their adsorption to the zinc crystal surface. According to a recent theory,[4] a partial reduction in step velocity may be expected for a given surface concentration of immobile surface impurities. The Bureau calculations showed some evidence of this effect.

[4] See N. Cabrera and D. Vermilyea in "Growth and Perfection of Crystals," edited by R. H. Doremus, B. W. Roberts, and D. Turnbull, New York, John Wiley & Sons, Inc., 1958, p. 393.

Results thus far obtained in experiments with very pure potassium distilled in an ultra-high vacuum are in contrast to those of other investigators[5] who found that surface nucleation appears to limit the crystallization velocity of potassium. The Bureau study, although not yet complete, does not show such condensation lags, even at low supersaturations.

The mercury whiskers now being investigated are single crystals of only ¦100 A or so in thickness, and from 5 to 50 microns in length. Because these whiskers are extremely strong single crystals, they may be observed by an electron field-emission microscope during growth. At a magnification of about 300,000×, their growth velocity is being measured directly with this technique. To obtain quantitative information on the effect of impurities on crystal growth, future work will be undertaken to measure the growth kinetics of metal crystals in the presence of known amounts of foreign gas molecules.

OBLIQUE-INCIDENCE RIOMETER ANTENNA

A special antenna has been developed by the National Bureau of Standards Boulder Laboratories to serve as the receiving antenna (50 Mc/s) for a relative ionospheric opacity meter (riometer). The riometer-antenna combination is being used in Alaska as part of the Bureau's investigation of auroral transmission loss. As no existing antenna met the performance and construction requirements specified for this particular use, this antenna, based on the design calculations of A. C. Wilson, was constructed.[6]

One of the main design requirements was that the main lobe of the antenna be 23 deg. above the horizon. A stacked array of three dipoles was selected, from both technical and economical considerations, as the antenna arrangement to be used. To achieve the 23-deg. angle of arrival requirement, calculations were made which placed the lowest dipole 0.64 wavelength above the ground, with the other two dipoles displaced vertically at odd multiples of 0.64 wavelength.

A number of other criteria had to be considered in the final design. The half-power beamwidth in the vertical plane could not exceed 10 deg.; the front-to-back ratio was to be 13 db, or higher; and side lobe levels had to be at least 10 db, below the maximum response in both the E- and H-plane. As the antenna was to be used in Alaska, the construction was to be simple and rugged.

Once the basic 3-level design had been established, it remained to incorporate reflectors to provide the desired directivity in the *E*-plane.

[5] "Die Verdampfungs-und Kondensationgeschwindigkeit des festen Kaliums," by F. Hock and K. Neumann, *Z. phys. Chem.*, Vol. 2, p. 241 (1954).

[6] For further technical details, see "Obique Incidence Receiving Antenna Array for a Relative Ionospheric Opacity Meter," by A. C. Wilson, NBS Tech. Note 78, available from the Office of Technical Services, U. S. Dept. of Commerce, Washington 25, D. C. (50¢).

As a maximum-gain single-reflector dipole has only a 5½-db front-to-back ratio, it was necessary to devise a multiple reflector of simple construction having the desired characteristics.

In order to determine experimentally the optimum reflector arrangement, the series of measurements was made using a scaled version of the folded dipole. Results of these determinations, made with both different numbers and arrangements of reflectors, indicated that the best configuration consists of two rod-shaped aluminum reflectors parallel to the ground and vertically displaced from one another by 0.4 wavelength, with the dipole, parallel to the reflectors, completing an open "prism." The dipole, somewhat shorter than the reflectors, is separated from the plane of the reflectors by 0.2 wavelength.

From the dimensions of the scaled model, two complete antenna arrays were constructed and adjusted to an impedance of 52 ohms/dipole unit. After final testing, the antennas were sent to Alaska, where they are currently in use.

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THE FRANKLIN INSTITUTE

MINUTES OF STATED MEETING

NOVEMBER 15, 1961

The Stated Meeting of The Franklin Institute was held at 8:15 P.M. in Franklin Hall, following a reception and dinner at which approximately 200 members and guests were present.

Wynn Laurence LePage, President, called the meeting to order and announced that the minutes of the Stated Meeting of October 18 will be published in the November issue of the JOURNAL and will be presented for approval at the next Stated Meeting of The Franklin Institute.

The President said we were gathered tonight to pay tribute to one of America's outstanding industrialists, Eugene Holman, retired Chairman of the Board of Directors of the Standard Oil Company (New Jersey) who will receive the Vermilye Medal—the only non-scientific award bestowed by The Franklin Institute—for his long and markedly successful career as an industrial manager.

The President introduced Dr. Francis J. Chesterman, a member of the Board of Managers of The Franklin Institute, Chairman of the Vermilye Medal Committee, and past President of the Bell Telephone Company of Pennsylvania, who presented Mr. Holman for the award.

The President presented the Vermilye Medal and Certificate of Award to Mr. Holman, and introduced him as the speaker.

Mr. Holman spoke on "The Importance of Technical Education in Industrial Management." His talk was received with considerable enthusiasm.

After expressing our deep and grateful appreciation to Mr. Holman for being with us and for his excellent talk, the President adjourned the meeting at 9:40 P.M.

WILLIAM F. JACKSON, JR.
Secretary

NOTE: The proceedings of the presentation ceremony will be published in the January, 1962, issue of the JOURNAL OF THE FRANKLIN INSTITUTE.

NEW BOOKS IN THE FRANKLIN INSTITUTE LIBRARY

CHEMISTRY AND CHEMICAL ENGINEERING

THE ELECTRICAL DOUBLE LAYER AROUND A SPHERICAL COLLOID PARTICLE, by A. L. Loeb. MIT, 1961.

PHYSICAL CHEMISTRY OF MACROMOLECULES, by C. Tanford. Wiley, 1961.

INTERFACIAL PHENOMENA, by J. T. Davies. Academic, 1961.

PRINCIPLES AND APPLICATIONS OF PAPER ELECTROPHORESIS, by C. Wunderly. Elsevier, 1961.

CYCLONES IN INDUSTRY. Elsevier, 1961.

HANDBOOK OF ORGANOMETALLIC COMPOUNDS, by H. C. Kaufman. Van Nostrand, 1961.

ELECTRICAL ENGINEERING

NATIONAL SYMPOSIUM ON MACHINE TRANSLATION: PROCEEDINGS. Prentice-Hall, 1961.

TRANSIENT CIRCUIT ANALYSIS, by Y. Ku. Van Nostrand, 1961.

FUNCTIONAL CIRCUITS AND OSCILLATORS, by H. J. Reich. Van Nostrand, 1961.

TRANSISTORS AND ACTIVE CIRCUITS, by J. G. Linvill. McGraw-Hill, 1961.

HANDBOOK OF TRANSISTOR CIRCUIT DESIGN, by K. A. Pullen. Prentice-Hall, 1961.

HISTORY OF SCIENCE AND TECHNOLOGY

A BIBLIOGRAPHY OF THE HONOURABLE ROBERT BOYLE, by J. F. Fulton. 2nd ed. Clarendon Press, 1961.

THEORIES OF SCIENTIFIC METHOD, by R. M. Blake. University of Washington Press, 1960.

GALILEO IN CHINA, by P. M. d'Elia. Harvard University Press, 1960.

MATHEMATICS

A FIRST COURSE IN MATHEMATICAL STATISTICS, by C. E. Weatherburn. 2nd ed. Cambridge University Press, 1961.

STATISTICAL INFERENCE FOR MARKOV PROCESSES, by P. Billingsley. University of Chicago Press, 1961.

THE PASSAGE PROBLEM FOR A STATIONARY MARKOV CHAIN, by J. H. B. Kemperman. University of Chicago Press, 1961.

METALLURGY

FUNDAMENTAL PRINCIPLES OF POWDER METALLURGY, by W. D. JONES. E. Arnold, 1960.

RESPONSE OF METALS TO HIGH VELOCITY DEFORMATION: PROCEEDINGS, by P. G. Shewmon. Interscience, 1961.

COLUMBIUM METALLURGY, edited by D. L. Douglass. Interscience, 1961.

PHYSICS

PLASTIC FLOW AND FRACTURE IN SOLIDS, by T. Y. Thomas. Academic, 1961.

THE THIRD LAW OF THERMODYNAMICS, by J. Wilks. Oxford University Press, 1961.

DISPERSION RELATIONS, edited by G. R. Screaton. Interscience, 1961.

DYNAMICS OF REAL FLUIDS, by E. G. Richardson. 2nd ed. E. Arnold, 1961.

URSI HANDBOOK OF IONOGRAM INTERPRETATION AND REDUCTION, edited by W. R. Piggott. Elsevier, 1961.

TABLES OF BLACKBODY RADIATION FUNCTIONS, by M. Pivovonsky. Macmillan, 1961.

PRINCIPLES OF CYCLIC PARTICLE ACCELERATORS, by J. J. Livingood. Van Nostrand, 1961.

THEORY OF ELASTIC STABILITY, by S. Timoshenko. 2nd ed. McGraw-Hill, 1961.

Fiber-Optic Face Plates for Light Transmission.—Two new image orthicons with fiber-optic face plates that eliminate the requirement for lenses have been developed by the General Electric Company.

Use of the fiber-optic face plates in some applications has achieved light transmission gains of up to 50 times that possible with conventional optics, according to engineers at G.E.'s Cathode Ray Tube Department in Syracuse.

The fiber-optic face plates, which replace standard glass plates, are fused bundles of insulated optical fibers—small pipes of dielectric material that conduct light—sealed into a 1½-in. disk. Fiber-optic face plates up to 3 in. in diameter are available.

Both I-O tubes use G.E.'s supersensitive thin-film target of magnesium oxide, and have produced clear pictures at low-light levels of well below 10^{-6} foot-candles.

The new fiber-optic I-O's are designated the ZL-7809 and the ZL-7810. The ZL-7809 has an S-10 photo surface that peaks at 4500 angstrom. The ZL-7810 uses an S-20 photo surface peaking at 4250 angstrom and has excellent red response.

The tubes can be built with spectral sensitivity from the ultraviolet to the infra-red. They also can be ruggedized to exceed military specifications for shock and vibration.

G.E. said applications for the fiber-optic image orthicons include aerial reconnaissance, satellite observation, medical television, and astronomy.

The fiber-optic I-O's are available in 30 to 90 days from G.E.'s Cathode Ray Tube Department, Syracuse, N. Y. Price depends on type of tube and such features as ruggedization and surface used.

New Protective Coating for Space Equipment.—A new non-conductive protective film coating for use on space equipment was introduced at the Air Force's Eighth Annual Science and Engineering Symposium held in San Francisco.

This revolutionary thin adherent nonporous film of pure silicon nitride discovery is the result of an in-house study to find a coating material that would be non-conductive and could resist high temperatures. Electronic equipment and metals destined for space use must be able to withstand extreme heat and nuclear radiation.

Several tests performed during the study showed that silicon nitride is capable of maintaining non-conducting properties up to a temperature of 600 C. Also, it is capable of protecting metal surfaces from atmospheric oxidation at much higher temperatures.

A condenser, placed in an oven with the temperature maintained at 500 C. for 400 hr., functioned satisfactorily both during heat exposure and after cooling to room temperature.

The coating could be used in industry wherever condensers and metals are exposed to high temperatures. Approximately one hundred industrial firms have expressed interest in the subject and several have inquired regarding the issuance of patent rights for manufacture of the condensers.

The film coating was revealed in a scientific paper, "Silicon Nitride Dielectric and Heat Protective Coating,"

authored by Dr. Charles R. Geesner and Mr. Charles R. Barnes. The tests were conducted at Aeronautical Systems Division, Air Force Systems Command, Wright-Patterson AFB, Ohio.

Micro-Thin Glass Film Seals.—A new high-volume method for sealing high reliability into microminiature diodes and transistors—using a film of glass over a thousand times thinner than a window pane—has been reported by the Components Division of International Business Machines Corporation.

The development holds promise of overcoming many cost and reliability problems inherent in producing microminiature devices. These devices are so small that a thousand are cut from a silicon wafer the diameter of a nickel.

The new IBM technique uses intense heat, over 1500 F., to produce a protective film of glass only one ten-thousandth of an inch thick. The high-volume advantage comes in the simultaneous sealing of thousands of microminiature devices.

Sealing against moisture and other atmospheric contaminants is essential because of the critical role played by the sensitive surface of a transistor or diode in determining the devices' performance.

With conventional methods, large numbers of such devices are made on small wafers of silicon. The wafers are then cut into individual "chip" transistors or diodes. In some cases, the devices get initial protection by being "passivated," or covered with a thin layer of silicon oxide before the wafer is cut apart. This layer of oxide offers some protection, but not enough for satisfactory reliability.

One way of increasing the protection is to encapsulate each chip separately in plastic or glass made at relatively low heating temperatures. Another way is to enclose single chips or assembled multi-chip circuits in hermetically-sealed metal containers. The new IBM technique eliminates the need for either the separate chip encapsulation or the metal containers.

The IBM method begins with conventional fabrication of diodes or transistors on silicon wafers, followed by the oxide coating process. At this point, a special glass powder is applied to the oxidized surface, and the entire wafer is fired at more than 1500 F. The result is the microsopically thin film of chemically resistant glass with a smooth, pinhole-free surface. The wafer is then cut with an ultrasonic "knife" into the tiny diodes or transistors, each retaining its permanent glass seal. Electrical contact to the devices is made through small holes etched through the glass and oxide.

The new development was described in Detroit at the Electrochemical Society Semiconductor Symposium by Dr. John A. Perri from a paper, "Surface Protection of Silicon Devices with Glass Films," by Dr. Perri, Dr. William A. Pliskin, Dr. Jacob Riseman, and Mr. Herbert S. Lehman, all of IBM's Components Division, Poughkeepsie, N. Y.

Hydraulic Biopsy Apparatus.—Doctors at The University of Michigan Medical Center have developed a new bite-size apparatus that will take tiny samples of living tissue from a patient's small intestine without surgery. Its use may cut down the need for expensive exploratory operations in suspected stomach cancer and other disorders of the digestive system.

The instrument is called a "hydraulic biopsy apparatus." Its business end, attached to a length of soft plastic tubing, is a stainless steel capsule smaller than a piece of rock

candy, which is swallowed by the patient. Inside the capsule is a razor sharp cylinder that is activated by hydraulic pressure transmitted down the plastic tube. On each motion, it crosses a small opening in the capsule and slices off a microscopic layer of the lining of the intestine. The sample is then washed up through the plastic tube so it can be analyzed by the attending physician. Any number of tissue samples can be taken before the capsule is removed.

About a dozen different models of the capsule have been made, all of them hand-crafted. They range in size from $1\frac{1}{2}$ in. long to $\frac{3}{4}$ in.

The apparatus can also be used to observe the effects of drugs and other substances on the lining of the stomach and small intestine. The doctors take a sample of the lining, then administer the substance to the patient, and take another sample without ever removing the tube.

This ability to take repeated samples is considered one of the advantages of the new apparatus over previous instruments. In addition, the Michigan instrument does not use springs or wires and needs a comparatively low amount of water pressure to operate.

No estimate has been made of the cost of the apparatus because the existing one is entirely handmade.

Gadget that Makes Fresh Water.—The Army has developed a handy new gadget that will make enough fresh water to keep survivors of sea disasters from dying of thirst. The new gadget, called the "sit still," was developed by the Army Engineer Research and Development Laboratories, Fort Belvoir, Va. It operates using the heat from the sun's rays or from the body of an individual sitting on it.

This "do-it-yourself" gadget consists of a sheaf of five sheets about the size of standard typewriter paper. The five sheets are a black plastic film on top, piece of paper toweling or cloth, then a water repellant screen, a sheet of aluminum foil and a cloth backing for the foil. A sponge to collect the fresh wayer completes the kit.

The fresh water is made by condensation. The five sheets are dipped in the ocean, excess water is drained and the aluminum foil wiped dry. Reassembled with the plastic film on top, the sheaf is exposed to the heat of the sun, or, if it's a cloudy day or night, by the heat from the survivor's body sitting on it.

The heat penetrates to the aluminum foil which is then cooled by the bottom salt-water soaked cloth. In the cooling process, a condensation of fresh water forms on the foil. The survivor uses the sponge to soak up the water, which may be only a few drops, but enough to keep him alive. The efficiency can be increased by using additional sheets of toweling, screen and foil. With additional sets of sheets, a survivor can obtain about a pint of water in 16 hours.

Mobidac, New Data System.—Portability, accuracy and economy are features of Mobidac, a new portable, mobile data acquision system, containing all the capability of a conventional multi-rack data gathering installation, which is announced by Systems Engineering Laboratories, Incorporated, Fort Lauderdale, Fla. Mobidac is declared to offer cost savings up to 50 per cent.

The new Mobidac system has wide applications in defense and in many industrial fields, according to William W. Dodgson, president of S.E.L. Measurement of pressures, temperatures and strains in oil refineries,

chemical processes, medical electronics, automotive, shipborne tests, rocket engine and aircraft testing programs are just a few of its uses.

The Mobidac system also has use in quality control and process monitoring operations, he declared. Analog represented parameters such as density and pressure can be digitized and recorded on Mobidac for later computer analysis of standard deviation, variance, quantities, mean values and others.

The standard Mobidac accepts 48 input data channels directly from transducers at full scale levels at low millivolts. These inputs are multiplexed and digitized into binary or BCD codes and then recorded on magnetic tape. Output tapes from Mobidac are compatible with all major computers with computer compatibility guaranteed.

The Mobidac consists of the Systems Engineering Laboratories' model LL-1 low level multiplexer, the ADC-1B Analog-to-Digital Converter, a logic/control unit, and a tape transport. Except for the tape unit, all these components were developed on a company-sponsored development program, and all are marketed as standard proprietary products.

According to S.E.L. engineers, Mobidac brings new levels of economy and reliability to the data acquisition field. Its low-level commutation technique results in elimination of individual d-c amplifiers on each channel. Cost savings over conventional systems for these components alone is approximately $50,000 and $100,000 respectively for 50 and 100 channel systems. The standard Mobidac has 48 channel capacity but is supplied with over 100 channels on an option basis.

Easy to operate, Mobidac is designed for flexible field, plant or laboratory use.

Medical X-Ray Gloves.—A superior medical X-ray protective glove made of lead-coated neoprene is an outgrowth of atomic energy work and offers three outstanding advantages:

1. It is the first X-ray glove to be to be sold with a six months' warranty on performance.
2. It not only provides superior protection to the radiologist or technician wearing it but allows greater dexterity, freedom of motion and manipulation during therapy because of its flexibility and tactility.
3. It can be disinfected or cleaned with soaps, detergents or chemical solutions without damage.

The new Rad-Bar medical X-ray gloves are made of Du Pont neoprene in a series of seamless plies, by an exclusive process developed by Charleston Rubber Company, Charleston, S. C. Smooth neoprene outer and inner surfaces surround the middle plies of lead-loaded neoprene. The outstanding protection of the gloves is provided by permanently and evenly dispersed lead particles that insure homogeneous opacity to diagnostic x-radiation (guaranteed lead equivalent 0.5 mm minimum).

The balanced properties offered by neoprene make possible many of the new glove's qualities. Neoprene's superior resistance to deterioration from ozone is a major advantage in its use around x-ray machines. Its flexibility contributes greatly to the increased sensitivity of these gloves. Doctors may actually handle syringes and hypodermic needles while wearing these gloves during therapy.

Unlike ordinary X-ray gloves, the Rad-Bar medical X-ray glove will not crack despite repeated flexing and it has no seams where cracks can occur. The old style gloves, often made with layers of leather, lead

rubber, and flannel, or leather and lead foil, are bulky, clumsy and unwieldy to wear. The Rad-Bar gloves are contour shaped to fit the hand for maximum comfort.

Red in color, the gloves have a black lining, and are offered in four sizes, including an extra small size for women, the first time such a size has been available in x-ray gloves. Two pairs of absorbent cotton innereliners are supplied with each pair of gloves.

Dynaquad, New Switching Device.—The development of the Type 2N1966 Dynaquad, a germanium, alloy junction PNPN switching device with triggered turn on and turn off at its base, has been announced by Tung-Sol Electric Inc., Semiconductor Division. The operation of the Dynaquad can be compared to the circuit equivalent of two complementary transistors, an NPN and a PNP, connected together. Because of its inherent bistable nature and its switching speed in the megacycle range, the Dynaquad can be used very efficiently in computer and control circuits or wherever circuits employing digital techniques are used. In a simple flip-flop circuit, one Dynaquad can replace as many as seven conventional components.

The alloy junction design of the Dynaquad makes possible a minimum emitter-to-base breakdown rating of 20 volts. Peak collector current is 3 amperes with a minimum pulse width of 100 μsec and a maximum repetition rate of 300 pps. Collector dissipation is 120 milliwatts. With an I_c of 50 ma and R_{be} at 1k, base turn on current is 0.5 ma maximum; base turn off current is 12 ma maximum with an I_c of 20 ma and R_{be} at 10k. Both turn on and turn off times are in the 0.1 μsec range. Dynaquad sustaining current is 20 ma maximum.

The Type 2N1966 Dynaquad is available in a standard hermetically sealed TO-5 package that has the semiconductor base element connected directly to the case to increase thermal efficiency. Operating temperature of the unit is from -65 C. to $+75$ C.

Packaged Power.—Unique uses of "packaged power" in science, research, and industry were exhibited by the Ramset Fastening System at the recent American Rocket Society Show in the New York Coliseum.

"Packaged power" is the application of the energy of a fired cartridge to perform a specific job. Cartridge-actuated devices are used to drive studs into steel or through other surfaces; shape and punch holes in metals; start jet engines; eject seats from airplanes; separate the stages of launched missiles.

One of the applications illustrated at the Ramset exhibit is metal forming. In metal forming, cartridges generate gases directly into the volume of the part to be formed and force the metal into the shape of the surrounding die.

The principal commercial application of "packaged power" is the powder-actuated fastening tool used extensively in the construction industry. Ramset tools utilize the energy of a fired blank cartridge to set threaded studs or drive pins into concrete or as much as one-inch of steel by a simple pull of the tool's trigger.

Ramset, part of the Winchester-Western Division, Olin Mathieson Chemical Corporation, pioneered the commercial use of powder-actuated tools in this country in 1947.

The varied applications of "packaged power" are described in a 36-page technical bulletin available from Ramset Fastening System, Winchester-Western Division, New Haven 4, Conn.

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